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Book of Abstracts

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Joint TMD - GPD - HELCITY - Future session EU timezone / 1

Exclusive Double Drell-Yan factorization and GTMDs

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In this talk we show how to apply the Soft-Collinear Effective Theory formalism to factorize the Exclusive Double Drell-Yan process, which gives access to Generalized TMDs as well as double TMDs. We discuss the relevance of the soft factor in the factorization theorem and its role in the definition of the GTMDs.

Fundamental Symmetries and and Spin Physics Beyond the Standard Model / 2

About toroidal model of leptons in space-time film theory

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Nonlinear field model of extremal space-time film is considered [1-3]. Its space-localized solution in toroidal coordinates with periodic dependence on time is investigated. In particular, we consider the field configuration having a form of the twisted lightlike soliton moving along the singular ring of the coordinate system. The solutions in the form of twisted lightlike solitons was considered in the work [1]. As was shown in this work, the subclass of such solitons can be conformed to real photons. In the present talk, we consider approximate time-periodic toroidal solutions. The approximate solutions are represented in the form of finite Fourier sums on the circular wave phase and the polar toroidal coordinate. The dependence of the solution on the radial toroidal coordinate is approximated by a fractional-rational function from the exponent of the coordinate. The phase of the circular wave is linearly dependent both on time and the azimuthal toroidal coordinate. The obtained solutions have the electrical charge and finite energy and angular momentum or spin. The question as to the relation these solutions to leptons is considered.

[1] A.A. Chernitskii, Lightlike shell solitons of extremal space-time film, Journal of Physics Communications, 2(2018)105013.
[2] A.A. Chernitskii, About long-range interaction of spheroidal solitons in scalar field nonlinear model, Journal of Physics: Conference Series, 938(2017)012029.
[3] A.A. Chernitskii, Lightlike solitons with spin, Journal of Physics: Conference Series, 678(2016)012016.
[4] A.A. Chernitskii, About toroidal soliton-particle of extremal space-time film, Journal of Physics: Conference Series, 1435(2020)012054.

Acceleration, Storage and Polarimetry of polarized Beams / 4

LEAP: Polarized Electron Beams from LPA and their Polarimetry

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In recent years, Laser Plasma Acceleration (LPA) has become a promising alternative to conventional RF accelerators. However, so far, it has only been theoretically shown that polarized LPA beams are possible.
The LEAP (Laser Electron Acceleration with Polarization) project at DESY aims to demonstrate this experimentally for the first time, using a prepolarized plasma target.
The electron polarization will be measured with photon transmission polarimetry. It makes use of the production of circularly polarized Bremsstrahlung during the passage of the electrons through a suitable target. The photon polarization is then measured with the aid of the transmission asymmetry related to the magnetization direction of an iron absorber.
In this contribution an overview of the LEAP project and the generation of polarized beams will be given and simulation studies and a design for the polarimeter will be presented.

Future facilities and experiments / **5**

The Central Role of Beam Polarization at Future e+e- Linear Colliders

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In e+e- collisions at energies above the Z resonances, left- and
right-handed polarized electrons and positrons are essentially
different species whose cross sections differ by order-1 factors.
This implies that beam polarization can be used as a tool to uncover many aspects of the physics that these colliders will study. This talk will present a wide variety of examples illustrating this point, from the determination of the structure of the Higgs boson couplings, to the search for new s-channel resonances, to the enhancement of the collider luminosity for Vector Boson Fusion reactions. It will also discuss the use of separately adjustable electron and positron polarization to control backgrounds and understand the magnitude of systematic uncertainties.

Fundamental Symmetries and and Spin Physics Beyond the Standard Model / **6**

The use of beam polarization in the search for dark matter at the ILC

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The International Linear Collider has the opportunity to discover dark matter particles in the monophoton signature e+e- -> gamma +(missing). The sensitivity to new physics in this channel depends crucially on the control and correct estimation of backgrounds. This talk will explain how beam polarization can be used at the ILC to improve the reach of this search.

Future facilities and experiments / **7**

Interplay of beam polarisation and systematic uncertainties in electroweak precision measurements at future e+e- colliders

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Future high-energy e+e- colliders will provide some of the most precise tests of the Standard Model. Statistical uncertainties on electroweak precision observables and triple gauge couplings are expected to improve by orders of magnitude over current measurements. This provides a new challenge in accurately assessing and minimizing the impact of experimental systematic uncertainties. Beam polarization may hold a unique potential to isolate and determine the size of systematic effects. So far, studies have mainly focused on the statistical improvements from beam polarisation. This study aims to assess, for the first time, its impact on systematic uncertainties. A combined fit of precision observables, such as chiral fermion couplings and anomalous triple gauge couplings, together with experimental systematic effects is performed on generator-level differential distribution of 2-fermion and 4-fermion final-states. Different configurations of available beam polarisations and luminosities are tested with and without systematic effects, and will be discussed in the context of the existing projections on fermion and gauge boson couplings from detailed experimental simulations.

Form Factors and GPDs / **9**

Spin Density Matrix Elements in Exclusive Muoproduction of ρ^0 and ω Mesons at COMPASS

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We will present results on Spin Density Matrix Elements (SDMEs) measured in hard exclusivsive muoproduction of ρ^0 and ω mesons on the proton at COMPASS using 160 GeV/c polarised μ^+ and μ^- beams scattering off a liquid
hydrogen target. The measurements cover the range 5 GeV/c^2 $< W <$ 17 GeV/c^2, 1.0 (GeV/c)^2 $< Q^2 <$ 10.0 (GeV/c)^2 and 0.01 (GeV/c)^2 $< p_T^2 <$ 0.5 (GeV/c)^2. Here, Q^2 denotes the virtuality of exchanged photon, W the mass of final hadronic system and p_T the transverse momentum of the vector meson with respect to the virtual-photon direction. The measured non-zero SDMEs for transitions of transversely polarised virtual photons to longitudinally polarised vector mesons ($\gamma_T \to V_L$) indicate a considerable violation of s-channel helicity conservation. Additionally, for ρ^0 production we observe a dominant contribution of natural-parity-exchange transitions and a small contribution of
unnatural-parity-exchange transitions observed only at small values of W. On the contrary,the contribution of unnatural-parity-exchange for ω production is significant. It decreases with increasing W, being still non-negligible at the largest W values accessible at COMPASS. The results provide an important input for modelling Generalised Parton Distribution (GPDs). In particular, they may allow to evaluate in a model-dependent way the role of parton-helicity flip GPDs ("transversity GPDs") in exclusive ρ^0 and ω production.

Transverse Momentum Structure (TMD) / **10**

Measurement of Drell-Yan Cross-Section in COMPASS

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The COMPASS experiment at CERN performed in 2015 and 2018 Drell-Yan measurements using a 190 GeV negative pion beam scattering off a NH3 target and nuclear aluminium and tungsten targets. We will present the differential cross section obtained from that measurement in the kinematic in x-Feynman, transverse momentum, and mass. The results will be valuable input for constraining parton distribution functions (PDFs) of the pion. We will present preliminary results on Drell-Yan cross sections and compare them to fixed-order QCD calculations with different pion PDFs. The kinematic dependence of nuclear effects in Drell-Yan production will be investigated by comparing the cross sections from three targets of different nuclear mass.

Form Factors and GPDs / **11**

Deeply Virtual Compton Scattering at COMPASS

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Deeply Virtual Compton Scattering (DVCS) is the golden exclusive reaction to study Generalized Parton Distributions (GPDs). Such exclusive measurements were performed at COMPASS in 2016 and 2017 at the M2 beamline of the CERN SPS using the 160 GeV muon beam scattering off a 2.5m long liquid hydrogen target surrounded by a barrel-shaped time-of-flight system to detect the recoiling target proton. The scattered muons and the produced real photons were detected by the COMPASS spectrometer, which was supplemented by an additional electromagnetic calorimeter for the detection of large-angle photons.
The DVCS cross section and its dependence with respect to the squared four-momentum transfer are extracted from the sum of cross-sections measured with opposite beam charge and polarization. The goal of the measurement is to determine the transverse extension of the partons in the specific Bjorken x domain of COMPASS between valence quarks and gluons. The analysis method and preliminary results of the long run will be discussed.

Form Factors and GPDs / **12**

Exclusive pi0 muoproduction at COMPASS

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Hard Exclusive Meson Production and Deeply Virtual Compton Scattering (DVCS) are very promising reactions to study Generalized Parton Distributions (GPDs). Such exclusive measurements were performed at COMPASS in 2016 and 2017 at the M2 beamline of the CERN SPS using the 160 GeV muon beam scattering off a 2.5m long liquid hydrogen target surrounded by a barrel-shaped time-of-flight system to detect the recoiling target proton. The scattered muons and the produced real photons were detected by the COMPASS spectrometer, which was supplemented by an additional electromagnetic calorimeter for the detection of large-angle photons.
Exclusive pi0 production is the main source of background for DVCS measurement, while it provides complementary information for parametrization of GPDs. We will report on preliminary results on exclusive pi0 production cross section and its dependence on the squared four-momentum transfer and on the azimuthal angle between the scattering plane and the pi0 production plane. This reaction is aiming to constrain the GPDs, in particular chiral-odd ("transversity") GPDs.

Form Factors and GPDs / **14**

Measurements of the exclusive neutral pion electroproduction at Jefferson Lab Hall A experiment E12-06-114

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Generalized Parton Distributions (GPDs) provide a 3D picture of the nucleon by correlating the longitudinal momentum to the transverse position of the partons inside of it. In addition to the chiral-even GPDs, the Deeply Virtual Meson Production (DVMP) also gives access to the chiral-odd (transversity) GPDs and has been providing inputs for the understanding of them. The exclusive production of π^0, in the Bjorken limit, is expected to be dominated by the contribution of the longitudinally polarized virtual photon that involves only the chiral-even GPDs, but it turned out not to be the case as shown by the previous data with limited reach in Q^2. The large contribution from the transversely polarized photon has been suggested to be the consequence of the convolution of the transversity GPDs and the Distribution Amplitudes (DA) of the π^0. The Jefferson Lab Hall A experiment E12-06-114 extended the kinematic coverage in the quark valence regime, and has measured the cross section of exclusive π^0 production off protons at large values of x_B (0.36, 0.48, and 0.60) and Q^2 (3.1 to 8.4 GeV^2). In this talk, the results of the E12-06-114 measurement will be presented.

Form Factors and GPDs / **15**

The deconvolution problem of deeply virtual Compton scattering

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Generalised parton distributions are instrumental to study both the three-dimensional structure and the energy-momentum tensor of the nucleon, and motivate numerous experimental programmes involving hard exclusive measurements. Based on a next-to-leading order analysis and a careful study of evolution effects, we exhibit non-trivial generalised parton distributions with arbitrarily small imprints on deeply virtual Compton scattering observables. This means that in practice the reconstruction of generalised parton distributions from measurements, known as the deconvolution problem, does not possess a unique solution for this channel. We further discuss the consequences on the extraction of generalised parton distributions from data and advocate for a multi-channel analysis.

Joint GPD - Future session / **16**

Accessing pion GPDs through the Sullivan process: is it feasible?

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The description of hadronic structure in terms of quark and gluon degrees of freedom is an open subject in physics. Great efforts are being devoted to this subject on both the theoretical and experimental sides. Triggered by existing plans to build new experimental facilities such as the EIC (BNL), and the need to properly interpret the data that are to come, the theoretical interest into the zoology of parton distribution functions is increasing. Among them, GPDs, which are known to parametrize the soft-physics taking place in DVCS, are expected to play a central role drawing three-dimensional images of hadrons. In this work we focus on the study of pions which, as Nambu-Goldstone bosons of QCD chiral symmetry breaking, provide one of the clearest windows onto the phenomenon of emergent hadronic mass (EHM). Herein we present a novel class of pion off-forward parton distributions: the so called postitivity-saturated GPDs, which relying on the covariant-extension fulfill all of the theoretical constraints required by QCD and benefit from a direct interpretation in terms of fundamental degrees of freedom: quarks and gluons. Exploiting them we are capable to obtain predictions for DVCS on pions to be probed through the Sullivan process at the EIC. We will show that a measurable asymmetry on the channel arise, therefore pushing optimism about probing pion structure at future electron-ion colliders.

Transverse Momentum Structure (TMD) / 17

Measurement of target spin (in)dependent asymmetries in dimuon production in pion-nucleon collisions at COMPASS

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COMPASS is a fixed-target high energy physics experiment located at the M2 beamline of the Super Proton Synchrotron at CERN. The study of the spin structure of the nucleon by measuring nucleon spin (in)dependent azimuthal asymmetries in Drell-Yan process is one of the main topics of the phase-II research programme of the experiment.

In 2015 and 2018 COMPASS performed Drell-Yan measurements using a 190 GeV π^- beam interacting with a transversely polarized NH_3 and unpolarized nuclear targets. The angular coefficients that describe the unpolarized part of the Drell-Yan cross section have been extracted from the data collected with tungsten target. The results obtained provide important information to study various perturbative and non-perturbative QCD effects. Performed polarized measurements of the Sivers and other transverse spin azimuthal asymmetries in Drell-Yan provide a unique possibility to test the (pseudo-)universality of the transverse momentum dependent parton distribution functions.

Measuring the same set of asymmetries in J/ψ production may give an alternative access to parton distribution functions and serve as input for the study of J/ψ production mechanisms.

In this talk recent preliminary results from the COMPASS Drell-Yan programme will be presented together with related measurements from other experiments and available model predictions.

Joint GPD - Future session / 18

Phenomenological assessment of proton mechanical properties from deeply virtual Compton scattering

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A unique feature of generalised parton distributions is their relation to the QCD energy–momentum tensor. In particular, they provide access to the mechanical properties of the proton i.e. the distributions of pressure and shear stress induced by its quark and gluon structure. In principle the pressure distribution can be experimentally determined in a model-independent way from a dispersive analysis of deeply virtual Compton scattering data through the measurement of the subtraction constant. In practice the kinematic coverage and accuracy of existing experimental data make this endeavour a challenge. Elaborating on recent global fits of deeply virtual Compton scattering measurements using artificial neural networks, our analysis presents the current knowledge on this subtraction constant and assesses the impact of the most frequent systematic assumptions made in this field of research. This study will pave the way for future works when more precise data will become available, e.g. obtained in the foreseen electron-ion colliders EIC and EIcC.

Joint GPD - Future session / **20**

Artificial neural network techniques in modelling of GPDs

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We discuss the use of machine learning techniques for the modeling of generalized parton distributions in view of their nonparametric estimation from experimental data. Current GPD extractions indeed suffer from a model dependence which lessens their impact and brings unknown systematics in the estimation of derived quantities like 3D tomography or angular momentum decomposition. On the contrary this new strategy to describe GPDs allows a flexible implementation of theory driven constraints and provides tools to keep model dependence at a minimum level. We also address aspects of a practical nature like the design and training of artificial neural networks suitable for this analysis. Getting a better grip on the control of systematic effects, our work will help GPD phenomenology to achieve its maturity in the precision era of GPD extractions opened by a new generation of experiments.

Transverse Momentum Structure (TMD) / **21**

Transverse momentum distributions in SIDIS at COMPASS

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As part of the investigation programme of the transverse spin and transverse momentum structure of the nucleon in semi-inclusive DIS processes, COMPASS has measured several transverse momentum distributions of the final state hadrons in DIS of 160 GeV/c muons off unpolarised targets.
Recently transverse momentum distributions were obtained by scattering the muons off an isoscalar target consisting of ⁶LiD beads immersed in a liquid ³He/⁴He mixture.
Here we present the first complete set of results for the transverse momentum distributions of hadrons produced in DIS off a liquid hydrogen target. These new results allow for a deeper investigation of the various kinematic dependences.
A novel leading-order analysis of the results, aiming to extract the mean value of the squared intrinsic transverse momentum of the quarks, is also presented.

Transverse Momentum Structure (TMD) / **22**

Azimuthal single- and double-spin asymmetries in semi-inclusive deep-inelastic lepton scattering by transversely polarized protons

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A comprehensive set of azimuthal single-spin and double-spin asymmetries in semi-inclusive leptoproduction of pions, charged kaons, protons, and antiprotons from transversely polarized protons is presented. These asymmetries include the previously published \hermes results on Collins and Sivers asymmetries, the analysis of which has been extended to include protons and antiprotons and also to an extraction in a three-dimensional kinematic binning and enlarged phase space. They are complemented by corresponding results for the remaining four single-spin and four double-spin asymmetries allowed in the one-photon-exchange approximation of the semi-inclusive deep-inelastic scattering process for target-polarization orientation perpendicular to the direction of the incoming lepton beam. Among those results, significant non-vanishing cos(□–□□) modulations provide evidence for a sizable worm-gear (II) distribution, □1□. Most of the other modulations are found to be consistent with zero with the notable exception of large sin□□ modulations for charged pions and □+

Transverse Momentum Structure (TMD) / **23**

Overview of HERMES results on longitudinal spin asymmetries

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The HERMES experiment has collected a wealth of data using the 27.6 GeV polarized HERA lepton beam and various polarized and unpolarized gaseous targets. This allows for a series of unique measurements of observables sensitive to the multidimensional (spin) structure of the nucleon, in particular semi-inclusive deep-inelastic scattering (SIDIS) measurements, for which the HERMES dual-radiator ring-imaging Cherenkov counter provided final-hadron identification between 2 GeV to 15 GeV for pions, kaons, and (anti)protons.
In this contribution, longitudinal single- and double-spin asymmetries in SIDIS will be presented. The azimuthally uniform double-spin asymmetries using longitudinally polarised nucleons constrain the flavour dependence of the quark-spin contribution to the nucleon spin. For a first time, such asymmetries are explored differential in three dimensions in Bjorken-x and the in the hadron kinematics z and □$h\perp$ (which respectively represent the energy fraction and transverse momentum of the final-state hadron) simultaneously. This approach increases the quark-flavour sensitivity and allows to probe the transverse-momentum dependence of the helicity distribution. The measurement

of hadron charge-difference asymmetries allows, under certain simplifying assumptions, the direct extraction of valence-quark polarisations. The azimuthal modulation of this double-spin as well as of the single-(beam)spin asymmetry probe novel quark-gluon-quark correlations through twist-3 distribution and fragmentation functions. Also here asymmetries are explored in several dimensions. Furthermore, in case of the beam-spin asymmetry, results for electro-produced protons and antiprotons have become available. The beam-spin asymmetries for pions are compared to similar measurements for pions at CLAS and unidentified hadrons at COMPASS.

Transverse Momentum Structure (TMD) / 24

Transverse spin asymmetries in inclusive ρ^0 muoproduction at COMPASS

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The study of the partonic and spin structure of the nucleon, using semi-inclusive measurements of hadron muoproduction in Deep Inelastic Scattering (DIS), is one of the main objectives of the COMPASS experiment at CERN. Within the QCD parton model approach, the nucleon structure in DIS can be parametrized in terms of Transverse Momentum Dependent (TMD) Parton Distribution Functions (PDFs), while the hadronization mechanisms are described by the so-called Fragmentation Functions (FFs). Specific convolutions of the TMD PDFs and FFs can be accessed through the measurement of various spin-dependent azimuthal asymmetries in hadron or dihadron productions in DIS. The production of vector mesons in SIDIS is potentially interesting to study the polarized fragmentation and related phenomena. However, this domain is largely unexplored.
In this talk preliminary COMPASS results for the first ever measurement of Collins and Sivers asymmetries in inclusive ρ^0 production will be shown. The analysis is based on the SIDIS data-set collected by COMPASS in 2010 using a 160 GeV/c longitudinally polarized μ^+ beam impinging on a transversely polarized NH_3 target.
The asymmetries were extracted as function of different kinematic variables and confronted with model expectations.

Transverse Momentum Structure (TMD) / 25

Beam-spin induced polarization of Λ and anti-Λ hyperons in semi-inclusive deep-inelastic scattering

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The beam-spin induced polarization of Λ and anti-Λ hyperons produced in deep-inelastic scattering of longitudinally polarized positrons from unpolarized nucleons has been investigated by the HERMES experiment at a positron beam energy of 27.6 GeV. Here, preliminary results are reported from data taken in the years
1999 to 2007, including in particular the two high-luminosity periods of 2006 and 2007 enlarging significantly the data set compared to previous HERMES analyses. The two spin-transfer coefficients D_LX and D_LZ, i.e., transverse and along the hyperon momentum direction, are extracted and studied as function of the relevant kinematic variables.

Transverse Momentum Structure (TMD) / 26

Azimuthal asymmetries in unpolarised semi-inclusive DIS at COMPASS

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In QCD the momentum and spin structure of the nucleon explored in hard-scattering reactions is described in terms of Transverse Momentum Dependent Parton Distribution Functions (TMD PDFs). The PDFs were studied primarily in the collinear approximation, until it was demonstrated that the intrinsic transverse motion of partons plays an important role.
In Semi-Inclusive Deep Inelastic Scattering (SIDIS) the non-zero transverse momentum of partons k_T induces azimuthal dependence of the cross-section and affects the transverse momentum distribution of the produced hadrons. The SIDIS cross-section contains three nucleon polarization independent azimuthal modulations that are related to different combinations of twist-2 or higher twist PDFs and fragmentation functions. Those are the so-called Cahn effect reflected in $cos(\phi_h)$ modulation, the $cos(2\phi_h)$ term related to the Boer-Mulders PDF and $sin(\phi_h)$ twist-3 effect known as beam-spin asymmetry.
In 2016 and 2017, the COMPASS experiment at CERN collected a large sample of DIS events using a longitudinally polarised 160 GeV/c muon beam scattering on a liquid hydrogen target. The azimuthal asymmetries $A_{UU}^{\cos(\phi_h)}$, $A_{UU}^{\cos(2\phi_h)}$ and $A_{UU}^{\sin(\phi_h)}$ have been extracted from part of the data. A new procedure has been developed to subtract a background coming from the decay of diffractively produced vector mesons. The results presented in this talk qualitatively agree with earlier COMPASS results obtained with an isoscalar target.

Transverse Momentum Structure (TMD) / **27**

Simulation of the polarized quark fragmentation within the string+3P0 model

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The recursive quantum mechanical string+3P0 model of polarized quark
fragmentation with pseudoscalar and vector meson production developed recently
has been implemented for the first time in a stand alone Monte Carlo program.
The program allows for a detailed study of the still unknown Collins effect for
vector meson production and of the effects of vector meson decays on the
Collins and dihadron asymmetries of the final observed hadrons.
In this talk we present the main results of the Monte Carlo simulations,
the comparison with the existing experimental data on SIDIS and e+e- annihilation to hadrons processes,
and predictions for possible new transverse spin asymmetries arising in the vector meson decay processes.
The theoretical aspects of the string+3P0 model are the subject of a different dedicated talk (X. Artru).

Future facilities and experiments / **28**

A Polarized Electron Beam Upgrade to SuperKEKB Enabling Precision Electroweak Measurements

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Consideration is being given to upgrading the SuperKEKB e^+e^- collider with polarized electron beams, which would open a new program of precision electroweak physics at a centre-of-mass energy of 10.58GeV, the mass of the $\Upsilon(4S)$. These measurements include $\sin^2\theta_W$ obtained via left-right asymmetry measurements of e^+e^- transitions to pairs of electrons, muons, taus, charm and b-quarks. The precision obtainable at SuperKEKB will match that of the LEP/SLC world average and will thereby probe the neutral current couplings with unprecedented precision at a new energy scale sensitive to the running of the couplings. At SuperKEKB the measurements of the individual neutral current vector coupling constants to b-quarks and c-quarks and muons in particular will be substantially more precise than current world averages and the current 3σ discrepancy between the SLC A_{LR} measurements and LEP A^b_{FB} measurements of $\sin^2\theta^{eff}_W$ will be addressed. This presentation will cover the necessary upgrades to SuperKEKB to achieve and measure the polarization in the SuperKEKB electron beam.

Acceleration, Storage and Polarimetry of polarized Beams / **29**

Measurement of Beam Polarization with Tau Polarimetry for a Potential SuperKEKB Upgrade

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A polarized electron beam is being considered as an upgrade for the SuperKEKB accelerator. Having a polarized beam at Belle II opens a new precision electroweak physics program, as well as improving sensitivity to dark sector and lepton flavour violating processes. In order to achieve a polarized beam at SuperKEKB a variety of hardware and technical challenges are being studied. The limiting factor on the precision of these future measurements is expected to be the uncertainty in the beam polarization achieved at the interaction point. The average beam polarization can be measured with high precision by making use of the relationship between beam polarization and the kinematics of tau decays.
In order to develop the tau polarimetry measurement technique, in preparation for a polarized electron beam at SuperKEKB, the data collected by BaBar is being analyzed. BaBar has a enough data to make a polarization measurement with a subpercent statistical uncertainty. This allows the dominant systematic uncertainties to be identified and studied, and the limiting factors for the precision of tau polarimetry to be established. As Belle II is similar in design to BaBar it is expected a similar or better level of precision can be achieved with sufficient data and the installation of polarized beams further motivated.

Acceleration, Storage and Polarimetry of polarized Beams / **30**

Can the EIC ^{3}He beam polarization be precisely measured by HJET?

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The requirements to hadron polarimetry at future Electron Ion Collider (EIC) include measurements of the absolute helion (^{3}He, h) beam polarization with systematic uncertainties better than $\sigma_P^{\rm syst}/P \leq 1\%$. Here, we consider a possibility to utilize the Polarized Atomic Hydrogen Gas Jet Target (HJET) for precision measurement of polarization of the ~ 100 GeV/n helion beam.

Since 2005, HJET serves to determine absolute proton beam polarization at the Relativistic Heavy Ion Collider with accuracy $\delta^{\rm syst}P/P \sim 0.5\%$. Concurrent measurement of the beam and target (the jet) spin correlated asymmetries allows one to relate the beam polarization $P_{\rm beam} = P_{\rm jet}\, a_{\rm beam}/a_{\rm jet}$ to the well known jet polarization $P_{\rm jet} \sim 96 \pm 0.1\%$. Thus, the proton beam polarization can be measured with actually no knowledge of the proton-proton analyzing power $A_{\rm N}^{pp}(t)$.

To adapt the method for the EIC helion beam, it is necessary to know the ratio of $p^{\uparrow}h$ and $h^{\uparrow}p$ analyzing powers $A_{\rm N}^{ph}/A_{\rm N}^{hp}$, which depends on the corresponding hadronic spin-flip amplitudes r_5^{ph} and r_5^{hp}. A prospect to derive these amplutudes from the proton-proton one, r_5^{pp}, measured at HJET will be discussed.

Potentially, results the ^{3}He beam polarization measurement can be affected by the helion breakup in the scattering. However, since only low energy recoil protons are detected at HJET, the breakup component in the acquired data is expected to be strongly suppressed. To figure out identification of the breakup events in the ^{3}He beam measurement at EIC and to evaluate elastic data contamination by such events, the HJET experimental data obtained with ~ 10 GeV gold and deuteron beams was analyzed.

Transverse Momentum Structure (TMD) / 31

THE STRING+3P0 MODEL OF HADRONIZATION

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The Lund String Fragmentation Model, widely used in Monte Carlo generators of jets, is extended to include the quark spin as a full quantum-mechanical degree of freedom, described by Pauli spinors. Such a model is needed to describe consistently the azimuthal asymmetries in jets from polarized quarks, like the Collins effect, di-hadron asymmetry and jet handedness.
The model is formulated in terms of quark propagators and quark-meson-quark vertices which are combinations of Pauli matrices. The basic assumption is that, when a string breaks, the created q-qbar pair is in the 3P0 state. This is implemented by a quark propagator proportional to mu+sigma_z sigma.k_T, where mu is a complex mass parameter. The model has been recently translated in a recursive Monte Carlo code for pseudoscalar meson production.
The introduction of vector mesons needed to complete the model requires a special recipe accounting for the entanglement between the spins of the meson and of the left-over quark. The longitudinal and transverse mesons are coupled to the quark line with two independent complex, constants G_L and G_T.
The expected properties are chiefly:
- Collins asymmetries of the same size but opposite signs for pi+ and pi-,
- di-hadron asymmetry linked to the Collins one,
- generation of jet handedness,
- vector mesons have Collins asymmetries whose signs depend on their linear polarizations,
- vector mesons can be generated with oblique (i.e., between transverse and longitudinal) polarizations. This is a new source of di-hadron asymmetry.

The main theoretical aspects of the model are presented in this talk, while the results of MC simulations and their comparison with existing data are the subject of a different dedicated talk (A. Kerbizi).

Joint TMD - GPD - HELCITY - Future session EU timezone / 32

TMD cross-section factorization for dijet production at the EIC

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We use soft collinear effective theory (SCET) to study a dijet production process in deep-inelastic-scattering (DIS), measuring the imbalance of the two hard probes in the Breit frame. In order to achieve factorization of the transverse momentum dependent (TMD) cross-section, we need to introduce a new soft function that we calculate at one-loop, regulating rapidity divergencies with the delta-regulator. We use consistency relations with heavy meson pair production in DIS to extend the anomalous dimension of the dijet soft function to three loops. We also provide phenomenological discussion and plots for this process, which is expected to be measured at the future EIC. The study of these processes could provide new knowledge of the TMD gluon distributions, to which they are sensitive.

Plenary Presentations / 33

Result of the neutron EDM starch at PSI

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We report on the result of the neutron EDM experiment which took data in 2015 and 2016 at PSIs ultracold neutron source. The neutron EDM is deemed to be one of the most sensitive probes of physics beyond the standard model. The experiment measured the precession frequency of spin polarized neutrons as a function of a strong electric field. The electric dipole moment of the neutrons leads to a linear dependence between those two quantities. After a blinded data analysis by two independent teams, we concluded that our results do not show this dependence within statistical uncertainties. We thus published a new upper limit of $d_n < 1.8\,10^{-26} e\,\mathrm{cm}$ [1]. The new result also significantly improves systematic uncertainties which will be discussed in detail. We will also give a future outlook on our new apparatus, n2EDM, which is currently set up at PSI.

[1] C. Abel et al. “Measurement of the Permanent Electric Dipole Moment of the Neutron” Phys. Rev. Lett. 124, 081803 (2020) 10.1103/PhysRevLett.124.081803.

Polarized Sources and Targets / 34

Plasma Lens: Prospects and designs of increased yield capture section of polarised e+ sources

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The ILC is an ambitious international collaboration with its positron source especially being at the forefront of pushing technological boundaries. Part of this enterprise has to be the optical matching device responsible for capturing positrons exiting the target and transforming them from a highly divergent beam with a small effective cross-section to a wide, parallel beam to be appropriate for the succeeding acceleration sections. This problem has been approached by different types of sophisticated coils like the quarter wave transformer and flux concentrator for many years now. Today considerations include the new principle based on an electric current in a plasma. This so called plasma lens creates a magnetic field, which is in theory especially qualified for optical matching due to its pronounced azimuthal component in contrast to the radial field of conventional devices. The prospect of increased yield would benefit a wide range of sources, particularly polarised sources.

Spin in Nuclear Reactions and Nuclei / **36**

Single-spin asymmetry in the reaction p^ + A(p) -> pi0 X

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Single-spin asymmetry (AN) in the reaction p^ + A(p) -> pi0 X with transversely polarized proton beam in pp and pA collisions is analyzed within the framework of the phenomenological model of chromomagnetic polarization of quarks (CPQ) [1-5]. Numerous existing data are compared with model calculations, including recent measurements of pp, pAl and pAu collisions with c.m. energy √s = 200 GeV [6]. There is good agreement between the data and calculations using the CPQ model. Detailed calculations of AN were performed depending on kinematic variables such as √s, pT, xF and the atomic weight of the target. In some kinematic regions, unusual behavior is expected, including asymmetry sign reversal and AN (xF) oscillation. This behavior can be studied in existing and future experiments.

References

[1] Phenomenology of single-spin effects in hadron production at high energies
V.V. Abramov (Serpukhov, IHEP). Dec 2008. 16 pp.
Published in Phys.Atom.Nucl. 72 (2009) 1872-1888, Yad.Fiz. 72 (2009) 1933-1949

[2] Single-spin physics: Experimental trends and their origin
V.V. Abramov (Serpukhov, IHEP). 2011. 8 pp.
Published in J.Phys.Conf.Ser. 295 (2011) 012086 Proceedings SPIN2010

[3] Polarization phenomena in hadronic reactions
V.V. Abramov (Serpukhov, IHEP). 2014. 4 pp.
Published in Phys.Part.Nucl. 45 (2014) 62-65 DOI: 10.1134/S106377961401002X
Conference: C12-09-17.3 Proceedings SPIN2012

[4] On the A-dependence of the neutron single-spin asymmetry in pA-collisions V.V. Abramov Published in: J.Phys.Conf.Ser. 938 (2017) 1, 012038 Proceedings DSPIN-17
[5] Possible studies at the first stage of the NICA collider operation with polarized and unpolarized proton and deuteron beams V.V. Abramov et al. e-Print: 2102.08477 [hep-ph] (Feb 16, 2021)

[6] J.Adam et al., STAR Collaboration, Phys.Rev. D 103 (2021) 072005 e-Print: 2012.07146 [nucl-ex]

Acceleration, Storage and Polarimetry of polarized Beams / **37**

Orbit Response Matrix Analysis for COSY - Model Optimization using LOCO

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The matter-antimatter asymmetry might be understood by investigating the EDM (Electric Dipole Moment) of elementary particles. A permanent EDM of a subatomic particle violates time reversal and parity symmetry at the same time and a discovery of a non-zero EDM would be a strong indication for physics beyond the Standard Model.

The JEDI-Collaboration (Jülich Electric Dipole moment Investigations) in Jülich has performed a direct EDM measurement for deuterons with the so called precurser experiments at the storage ring COSY (COoler SYnchrotron).

In order to understand the measured data and to disentangle an EDM signal from systematic effects, spin tracking simulations in an accurate simulation model of COSY are needed. Such an accurate model can be achieved by measuring the ORM (Orbit Response Matrix) of COSY and fitting the model ORM against the measured ORM using the LOCO (Linear Optics from Closed Orbit) technique. Therefore, the LOCO algorithm as well as a simulation model of COSY with all knowledge of COSY available has been implemented into the software library Bmad. First results
of the lattice optimization and the spin tracking simulations will be discussed.

Transverse Momentum Structure (TMD) / 38

Spin asymmetries in electron-jet production at the EIC

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The internal structure of jets has been an active research topic in QCD in recent years. In this talk, we propose to use one particular jet substructure - the so-called jet fragmentation function to study spin-dependent distribution and dynamics. In particular, we provide the general theoretical framework for studying the distribution of hadrons inside a jet by taking full advantage of the transverse-momentum-dependent distributions and polarization effects. The key development referred to as “polarized jet fragmentation functions’’, opens up new opportunities to study transverse momentum dependent (TMD) fragmentation functions via jets. Besides providing the theoretical understanding for the well-known Collins asymmetry for hadron in a jet, we also give additional examples involving polarization of Lambda baryons and pions inside the jet at the future Electron-Ion Collider.

Fundamental Symmetries and and Spin Physics Beyond the Standard Model / 39

Test of discrete symmetries with spin observables at J-PET

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The Jagiellonian PET (J-PET) detector is the only device which enables estimation of positronium spin axis together with determination of polarization of photons from positronium annihilation on the event-by-event basis. This allows to test angular correlations in the annihilations of the lightest leptonic bound system and explore a new class of discrete symmetry odd operators that were not investigated before. Such measurement is equivalent to a search for possible violation of combined charge, parity, and time-reversal symmetries as yet another approach for a test of New Physic. Positronium, a bound state of electron and positron, as the lightest matter-antimatter system and at the same time an eigenstate of the C and P operators is an unique probe in such endeavor. With first measurements demonstrating such capabilities we are able to reach the precision of CP and CPT tests at permill level. In the talk we will describe experimental techniques and new results of discrete symmetries tests in the decays of positronium in a whole available phase-space.

Fundamental Symmetries and and Spin Physics Beyond the Standard Model / 40

Novel mechanisms for the generation of EDMs in paramagnetic atoms and molecules via hadronic sources of CP violation

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Rapid advances in searches for the electron EDM have recently been achieved using paramagnetic molecules, with an improvement in sensitivity by more than 100-fold over the past decade alone **[1]**. In our recent paper **[2]**, we have identified novel mechanisms for the generation of EDMs in paramagnetic atoms and molecules via hadronic sources of CP violation. If the source of CP violation resides in the hadronic sector, then two-photon-exchange processes between electrons and the nucleus induce CP-odd semileptonic interactions, providing the dominant source of EDMs in paramagnetic systems instead of via the electron EDM. Unlike the nuclear Schiff moment mechanism in diamagnetic systems, the generation of a nucleon-number-enhanced CP-odd nuclear scalar polarisability can occur in all possible nuclei and is generally less sensitive to details of the underlying nuclear structure. Using the recent ACME EDM limit from paramagnetic ThO, we have derived bounds on the QCD theta term, proton EDM, isoscalar CP-odd pion-nucleon coupling, and colour EDMs of the light quarks.

References

[1] Andreev *et al.* (ACME Collaboration), Nature **562**, 355 (2018).
[2] Flambaum, Pospelov, Ritz and Stadnik, Physical Review D **102**, 035001 (2020).

Fundamental Symmetries and and Spin Physics Beyond the Standard Model / 41

muEDM: Towards a search for the muon electric dipole moment at PSI using the frozen-spin technique

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We propose an experiment to search for the permanent electric dipole moment (EDM) of the muon at the Paul Scherrer Institute (PSI), Switzerland, by employing the frozen-spin technique with a potential sensitivity of $6 \times 10^{-23}\ e \cdot \mathrm{cm}$ [1]. A muon EDM would violate CP symmetry and lepton flavor universality which makes the search an excellent test for physics beyond the Standard Model (SM). In the light of the recently reported combined 4.2σ deviation from the SM in the muon $(g-2)$ together with observed tensions in B decays, a dedicated muon EDM experiment is very attractive not only to further push EDM searches beyond to the first generation of fundamental particles, but also to probe the role of the lepton flavour universality in nature.

Several R&D studies are underway at PSI in preparation for a high precision experiment to measure the muon EDM. In 2019, the characterisation of the πE1 and μE1 beamlines at PSI, two potential beamlines to develop and host the experiment, were performed. The transverse phase space as well as polarisation of the μ^+ beam were measured up to 125 MeV/c to extract essential input parameters for ongoing Geant4 simulations of the proposed experiment. Multiple scattering of muon decay positrons would potentially influence strongly the design of the positron tracking scheme. Therefore, Coulomb multiple scattering of positrons in the momentum range below 85 MeV/c was studied in 2020 with a telescope consisting of 3 planes of MALTA CMOS pixel detectors. In this talk, I will present and discuss the current status and prospects of the muEDM experiment at PSI.

This work is supported by ETH Research Grant ETH-48 18-1.

[1] A. Adelmann *et al.*, Search for a muon EDM using the frozen-spin technique, arXiv:2102.08838 [hep-ex] (2021).

Plenary Presentations / **42**

Polarized target experiments at LHC

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A polarized gaseous target, operated in combination with the high-energy, high-intensity LHC beams and a highly performing LHC particle detector, has the potential to open new physics frontiers and to deepen our understanding of the intricacies of the strong interaction in the non-perturbative regime of QCD. Specifically, the LHCspin project aims to develop, in the next few years, innovative solutions and cutting-edge technologies to access spin physics in high-energy polarized fixed-target collisions using the LHCb detector. Given its forward geometry (2<□<5), the LHCb spectrometer is, in fact, perfectly suitable to cope with the forward kinematics of these collisions. Furthermore, being designed and optimized for the detection of heavy hadrons, it will allow to probe the nucleon's structure by exploiting new probes, such as inclusive production of c- an b-hadrons, and ideal tool to access, e.g., the essentially unexplored spin-dependent gluon TMDs. This configuration, with center-of-mass energies ranging from 115 GeV in pp interactions to 72 GeV per nucleon in collisions with ion beams, will allow to explore the nucleon's internal dynamics at unique kinematic conditions, by covering a wide backward rapidity region, including the poorly explored high x-Bjorken and high x-Feynman regimes. This ambitious task poses its basis on the recent installation of SMOG2, a storage-cell based unpolarized gas target in front of the LHCb spectrometer. With the installation of the proposed polarized target system, LHCb will become the first experiment delivering simultaneously unpolarized beam-beam collisions at 14 TeV and both polarized and unpolarized beam-target collisions at center-of-mass energies of the order of 100 GeV. The status of the LHCspin project is presented along with a selection of physics opportunities

Nucleon Helicity Structure / **43**

Measurement of longitudinal spin transfer of the $\Lambda(\bar{\Lambda})$ hyperon in longitudinally polarized $\mathrm{p}+\mathrm{p}$ collisions at $\sqrt{s} = 200$ GeV at RHIC-STAR

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Since the first surprising results on the spin structure of the proton by the EMC experiment in the late 1980s, much progress has been made in understanding the origin of the proton spin. However, the sea quark contribution to the proton spin, for example, the helicity distributions of the strange quark (anti-quark), $s(\bar{s})$, is still not well constrained by experimental data. Since the $s(\bar{s})$ is expected to carry a substantial fraction of the spin of the $\Lambda(\bar{\Lambda})$ hyperon, measurements of the longitudinal spin transfer, D_{LL}, of the $\Lambda(\bar{\Lambda})$ hyperon can thus shed light on the helicity distribution of the $s(\bar{s})$ and the longitudinally polarized fragmentation functions. In this talk, we will present the status of the $\Lambda(\bar{\Lambda})$ D_{LL} analysis using data collected at RHIC-STAR in 2015, for the pseudo-rapidity $|\eta| < 1.2$ and transverse momenta up to 8.0 GeV$/c$. The D_{LL} as a function of the longitudinal momentum fraction of the $\Lambda(\bar{\Lambda})$ hyperon in the jet is also investigated. This data set is about twice as large as the 2009 data used for the previously published D_{LL} results.In addition, the longitudinal double spin asymmetries, A_{LL}, of the $\Lambda(\bar{\Lambda})$ hyperon and the K^0_S meson are investigated, which are also expected to be sensitive to the $s(\bar{s})$ helicity distributions.

Transverse Momentum Structure (TMD) / **44**

Exploring the Quark Transversity and the Collins Fragmentation Functions using Polarized pp Collisions at STAR

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Understanding the internal spin structure of the nucleon still remains a challenge in strong interaction physics. Transversity, which describes the transverse spin structure of quarks in a transversely polarized proton, is still poorly constrained by experimental data. Since it is chiral-odd, it can only be accessed through channels that couple to other chiral-odd distributions, like the Collins fragmentation functions (so-called Collins effect) or the interference fragmentation functions.
Recently, a detailed calculation using the soft-collinear effective theory found that the Collins effect in pp collisions involves a mixture of collinear and transverse momentum dependent (TMD) factorization. The Collins effect provides a direct probe to the Collins fragmentation function and enables testing of its evolution, universality and factorization breaking in the transverse momentum dependent formalism.
In 2018, STAR published the first measurements of Collins asymmetries for charged pions in jets in polarized pp collisions at $\sqrt{s}$ = 500 GeV based on data taken during 2011. These measurements probe Q^2 scales one to two orders of magnitude larger than similar measurements in semi-inclusive deep-inelastic scattering (SIDIS) and the results are consistent with predictions based on global analyses of e^+e^- and SIDIS data.
In 2012 and 2015, STAR collected $\sim$14 pb^{-1} and $\sim$48 pb^{-1} of transversely polarized pp data at $\sqrt{s}$ = 200 GeV, respectively. These datasets provide the most precise measurement of the Collins effect in 200 GeV pp collisions to date, especially at the quark momentum fractions $0.1 \leq x \leq 0.4$. Preliminary results for Collins asymmetries of identified pions, kaons, and protons in jets in pp collisions at $\sqrt{s}$ = 200 GeV and comparisons to theory predictions will be presented.

Acceleration, Storage and Polarimetry of polarized Beams / **45**

Pellet target development for storage ring EDM polarimetry

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The JEDI (Jülich Electric Dipole moment Investigations) collaboration in Jülich is conducting a set of experiments at the COSY accelerator and storage ring, aiming to develop experimental techniques to measure the EDMs of charged particles, like proton and deuteron. One of the key elements of these experiments is the modular polarimeter (JEPO) with a special target system.

In the current configuration, horizontal and vertical block targets are used in the polarimeter. Targets are mounted on stepper linear actuators and dedicated hardware and software are used to control target movements during experiments. The EPICS based target control system can access accelerator and detector data and use them as a feedback for automatic target movement or finding the proper beam position for measurement. The system is controlled by the network interface using dedicated, user friendly GUI. It has several safety modules which consist of software and hardware interlock systems.

The work on a special target system, which will oscillate carbon pellets through the beam is ongoing. The frequency and the speed of oscillation must be variable to achieve the desired effective target density. This kind of target will require a specialised monitoring and control system, consisting of several electrical and mechanical parts. The system will include precise triggering, object detection, track reconstruction and data synchronization units. Control signals and data will be exchanged using a network interface, which will provide the ability to synchronize data of the target with other systems in the detector.

In this contribution achievements and experimental results will be summarized and ongoing activities towards the dedicated ballistic pellet target development presented.

Transverse Momentum Structure (TMD) / **48**

Factorized Approach to QED Radiation in Semi-inclusive Deep Inelastic Scattering

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Semi-inclusive deep inelastic scattering (SIDIS) is one of the key processes to extract transverse momentum dependent parton distributions (TMDs). An advantage of electrons is that they are much cleaner probes of nucleon structure than hadron beams, but, at the same time, electron scattering at large momentum transfer can be a source of considerable photon radiation, which can significantly distort the inferred nucleon structure. In this talk, I will present a new factorized approach to SIDIS, treating QED and QCD radiation on equal footing and providing a systematically improvable approximation to the extraction of TMDs. I will show how radiation effects prevent a well-defined "photon-hadron" frame, forcing one to use a two-step process to account for the radiation, and demonstrate how the QED contributions can be well approximated by collinear factorization. I will illustrate the utility of the new method by explicit application to transverse single spin asymmetries.

Transverse Momentum Structure (TMD) / 49

Towards leading-twist T-odd TMD gluon distributions

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We perform explorative analyses of the 3D gluon content of the proton via a study of polarized T-odd gluon TMDs at leading twist, calculated in a spectator model for the parent nucleon. Our approach encodes a flexible parameterization for the spectator-mass density, suited to describe both moderate and small-x effects. All these prospective developments are relevant in the investigation of the gluon dynamics inside nucleons and nuclei, which constitutes one of the major goals of new-generation colliding machines, as the Electron-Ion Collider, the High-Luminosity LHC, NICA-SPD, and the Forward Physics Facility.

Fundamental Symmetries and and Spin Physics Beyond the Standard Model / 50

EDM in Small Rings

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We will present a new design of highly specialized small storage rings for low energy polarized electron beams. The new design is based on the transparent spin methodology that cancels the spin precession due to the magnetic dipole moment at any energy while allowing for spin precession induced by the fundamental physics of interest to accumulate. The buildup of the vertical component of beam polarization can be measured using standard Mott polarimetry that is optimal at low electron energy. These rings can be used to measure the permanent electric dipole moment of the electron, relevant to CP violation and matter-antimatter asymmetry in the universe, and to search for dark energy and ultra-light dark matter.

Spin in Nuclear Reactions and Nuclei / 51

Roles of spin-dependent transitions in nuclei on astrophysical processes in stars

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Due to recent advances in shell-model studies on spin modes in nuclei, precise evaluations of Gamow-Teller (GT) strengths become feasible and electron-capture and β-decay rates in stellar environments have been updated.
The weak rates in sd-shell obtained with the USDB Hamiltonian are applied to nuclear Urca processes in O-Ne-Mg cores in stars with 8-10 solar masses [1,2]. The Urca processes for the nuclear pairs with A=23 and 25 are found to be important for the cooling of the core [1].
Here, the weak rates important for the Urca processes in accreted neutron star crusts [3] are investigated. The e-capture and β-decay rates are evaluated for the nuclear pair with A=31, ^{31}Al $\leftrightarrow$ ^{31}Mg, in sd-pf shell and the pair with A=61, ^{61}V $\leftrightarrow$ ^{61}Cr, in fp-gd shell. ^{31}Mg belongs to the island of inversion, where admixtures of sd- and fp-shells become important. Energy levels in ^{31}Mg are found to be well reproduced with the use of EEdf1 interaction obtained by the extended Kuo-Krensiglowa (EKK) method [4], which can properly treat Q-box calculations in two-major shells without divergence problems. The weak rates evaluated with the EKK method prove to lead to Urca processes.
The GT strengths in ^{61}V is evaluated with the GXPF1J Hamiltonian [5]. The calculated strength between the ground states of ^{61}V and ^{61}Cr is found to be consistent with the recent experimental data [6]. This suggests that the Urca process for the A=61 pair would be more moderate than considered before. Results with an extension to the fp-gd shell-model space will be also reported.
The weak rates in fp-shell obtained with the GXPF1J are applied to nucleosynthesis in Type Ia supernova explosions [7]. The electron screening effects are taken into account [8]. Overproduction problem of neutron-rich iron-group elements for the previous weak rates is found to be considerably suppressed.

[1] H. Toki, T. Suzuki, K. Nomoto, S. Jones, and R. Hirschi, Phys. Rev. C **88**, 015806 (2013).
[2] T. Suzuki, H. Toki, and K. Nomoto, ApJ. **817**, 163 (2016).
[3] H. Schatz, S. Gupta, P. Moller et al., Nature **50**, 62 (2014).
[4] N. Tsunoda, T. Otsuka, N. Shimizu, M. Hjorth-Jensen, K. Takayanagi, and T. Suzuki, Phys. Rev. C **95**, 021304 (R) (2017).
[5] M. Honma et al., J. Phys. Conf. Ser. **20**, 7 (2005).
[6] W. J. Ong et al., Phys. Rev. Lett. **125**, 262701 (2020).
[7] K. Mori et al„ M. A. Famiano, T. Kajino et al., ApJ. **863**, 176 (2018);
[8] K. Mori, T. Suzuki, M. Honma et al., ApJ **904**, 29 (2020).

Plenary Presentations / **52**

Electric Dipole Moment Measurements at Storage Rings

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Electric Dipole Moments (EDMs) of elementary particles, including hadrons, are considered as one of the most powerful tool to study CP-violation beyond the Standard Model. Such CP-violating mechanisms are searched for to explain the dominance of matter over anti-matter in our universe.

The talk will discuss EDM searches of charged hadrons in storage rings. Due to an EDM, the spin vector will experience a torque resulting in a change of the original spin direction which can be determined with the help of a polarimeter. Although the principle of the measurement is simple, the smallness of the expected effect makes this a challenging experiment requiring new developments in various experimental areas. Given the complexity of the project, a step wise approach is proposed[1)].

The talk will discuss activities at the existing storage ring COSY at Forschungszentrum J\"ulich, Germany.
The next step is the design of a 100\,m circumference prototype ring able to demonstrate
key technologies and components. These include simultaneous clockwise and counter-clockwise beam operation
with electrostatic bending elements and, by adding a magnetic field, the frozen spin technique.
The final step is the operation of a pure electric storage ring of about 500\,m circumference.
Other projects like a measurement of the muon EDM will also be discussed.

[1)] Storage ring to search for electric dipole moments of charged particles, Feasibility study , CPEDM collaboration, https://doi.org/10.23731/CYRM-2021-003

Low energy spin physics with lepton, photon and hadron probes / **53**

Coherent neutral-pion and eta-meson photoproduction on the deuteron

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The ηd threshold structure $\mathcal{D}_{\eta d}$ with a spin parity of 1^- has been experimentally studied in the $\gamma d \to \pi^0 \eta d$ reaction at $E_\gamma 1.15$ GeV. The structure is connected to the isoscalar S-wave two-body system between the nucleon N and nucleon resonance $N(1535)1/2^-$, or the chiral partner candidate of N. By incorporating the known isovector resonance $\mathcal{D}_{12}$ with a spin-parity of 2^+ in the $\pi^0 d$ channel, we decompose the ηd and $\pi^0 d$ invariant-mass spectra into the $\eta\mathcal{D}_{12}$ and $\pi^0\mathcal{D}_{\eta d}$ contributions. From the analysis of π^0 and η angular distributions, we determine the spin-parity of the first intermediate $\eta\mathcal{D}_{12}$ and $\pi^0\mathcal{D}_{\eta d}$ systems. The spin-parity of the major component is found to be 0^- in the $\pi^0\mathcal{D}_{\eta d}$ system, suggesting that some nucleon resonance contributes to $\pi^0\eta$ photoproduction on the nucleon. It should be noted that $\Delta(1700)3/2^-$ is the main contributor for the elementary $\pi^0\eta$ photoproduction. The talk will be based on [T. Ishikawa *et al.*, arXiv:2105.10887].

Nucleon Helicity Structure / **54**

Helicity quasi-PDFs in a large Nc nucleon

Authors: Hyeon-Dong Son[1]; Maxim Polyakov[1]; Asli Tandogan[1]

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We discuss the properties of the helicity quark quasi-distributions in the large Nc limit. Within the framework of the chiral quark-soliton model, we review the properties of the quasi-PDFs such as the sum rules and the positivity. Numerical results for quark and antiquark isovector helicity distributions are presented. Significant antiquark flavor asymmetry is observed in a wide range of nucleon momentum.

Nucleon Helicity Structure / **55**

Illuminating the nucleon spin

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I will discuss the extension of the nucleon spin sum rule to QCDxQED. I will present the QED corrections to the evolution of the quark and gluon helicity and orbital-angular-momentum (OAM) distributions, which are calculated for the first time, and the necessary inclusion of photon and lepton helicity and OAM distributions.

Transverse Momentum Structure (TMD) / 56

Transverse Spin Transfer of Λ and $\overline{\Lambda}$ Hyperons in Polarized p+p Collisions at $\sqrt{s} = 200$ GeV at RHIC-STAR

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The transverse spin transfer, D_{TT}, of Λ and $\overline{\Lambda}$ hyperons in p+p collisions is expected to be sensitive to the s and $\bar{s}$ quark transversity distributions in the proton and to the transversely polarized fragmetation functions. The STAR experiment has published the first measurement of the transverse spin transfer of Λ and $\overline{\Lambda}$ hyperons in transversely polarized p+p collisions at $\sqrt{s}$ = 200 GeV within pseudo-rapidity $|\eta| < 1.2$ and for the transverse momenta up to 8 GeV/c based on the data taken in 2012. In 2015, a data sample of p+p collisions at $\sqrt{s}$ = 200 GeV, about two times larger than the 2012 data, was collected. The preliminary result of the transverse spin transfer, D_{TT}, of Λ and $\overline{\Lambda}$ hyperon versus transverse momentum, based on 2015 data, will be presented. The status of investigating D_{TT} versus fractional momentum of the hyperon within a jet will also be reported.

Transverse Momentum Structure (TMD) / 57

Longitudinal and transverse polarizations of Λ hyperons in unpolarized SIDIS and e^+e^- annihilations

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We make a systemic study on the longitudinal polarization and two transverse polarizations of the Λ hyperons produced in unpolarized SIDIS and e^+e^- annihilation.

Recently, Belle collaboration measured the transverse polarization (P_N) of Λ hyperons in e^+e^- annihilation [1], which inspired three parameterizations of the $D_{1T}^{\perp}(z, p_T)$ fragmentation function [2-3] so far. Unlike the other two (DMZ and CKT parameterizations) [2], for the first time, our work (CLPSW parameterization) shows that the Belle data does not endorse isospin symmetry violation [3]. The future EIC experiment has the ability to change the target nucleons/nuclei. It can eventually test the isospin symmetry of the polarized fragmentation functions. We make predictions for the transverse polarization (P_N) of Λ with all three parameterizations in ep and eA scatterings. We obtain almost no nuclear modification effect with the isospin symmetric CLPSW parameterization at large-x. However, there is a distinct difference between the results for ep and eA scatterings in the isospin-symmetry-violating DMZ and CKT parameterizations. Therefore, the future EIC experiment can help distinguish different parameterization scenarios and ultimately solve this dispute.

Furthermore, the transverse polarization of the struck quark can be induced by the Boer-Mulders function from an unpolarized hadron. This transverse polarization will further translate to azimuthal asymmetries and polarizations of final state hyperons through chiral-odd fragmentation functions. Therefore, besides P_N, the Λ hyperons produced in unpolarized SIDIS are also polarized along the longitudinal direction (P_L) and the transverse direction inside the production plane (P_T). These two polarizations are azimuthal angle dependent. They disappear in the whole phase space average over the azimuthal angle. We present how to measure these polarizations in the future EIC and the current Belle experiments. We demonstrate their relations with the corresponding structure functions and the leading twist fragmentation functions [4].

Our study bridges the experimental observables to the polarized fragmentation functions. The future measurement at EIC and Belle can significantly improve our understanding of the hadronization mechanism.

References

[1] Belle Collaboration, Phys. Rev. Lett. 122 (2019), 042001 [arXiv:1808.05000].
[2] U. D'Alesio, F. Murgia and M. Zaccheddu, Phys. Rev. D 102 (2020), 054001 [arXiv:2003.01128]; D. Callos, Z.B. Kang and J. Terry, Phys. Rev. D 102 (2020), 096007 [arXiv:2003.04828].
[3] K.B. Chen, Z.T. Liang, Y.L. Pan, Y.K. Song and S.Y. Wei, Phys. Lett. B 816 (2021), 136217 [arXiv:2102.00658].
[4] K.B. Chen, Z.T. Liang, Y.K. Song and S.Y. Wei, arXiv:2108.07740.

Plenary Presentations / 58

Spin Physics Detector at NICA

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The Spin Physics Detector (SPD) is one of the two large setups at the NICA collider under construction at JINR (Dubna). The ultimate goal of the studies at SPD is measurement of different spin observables in polarized proton-proton, deuteron-deuteron and proton-deuteron collisions sensitive to the polarized gluonic structure of the nucleon at the luminosity up to 10^32 cm^-2*s^-1 and \sqrt{s} up to 27 GeV. SPD will consist of the superconducting magnetic system, silicon tracker based on the DSSD and MAPS technologies, straw mini-drift tubes tracker, time-of-flight system, electromagnetic «shashlyk»-type calorimeter, muon (range) and local-polarimetry systems. The high performance free-streaming DAQ system will be able to operate at the collision rate up to 4 MHz.

Spin in Nuclear Reactions and Nuclei / 59

Deuteron analyzing powers Ay, Ayy and Axx in dp- elastic scattering at large transverse momenta

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The results on the vector Ay and tensor Ayy and Axx analyzing powers in deuteron-proton elastic scattering at large transverse momenta are presented. These data were obtained at internal

target at JINR Nuclotron in the energy range 400-1800 MeV using polarized deuteron beam from new polarized ion source. New data on the deuteron analyzing powers in the wide energy range demonstrate the sensitivity to the short-range spin structure of the isoscalar nucleon-nucleon correlations.

Joint BSM - Accelerator - Future Session EU timezone / 60

Development of Iron Thin Films for Polarization Analysis of Ultracold Neutrons

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The TRIUMF Ultra-Cold Advanced Neutron (TUCAN) collaboration aims to measure the neutron electric dipole moment (EDM) with a sensitivity of $10^{-27} e \cdot \mathrm{cm}$ with a high-intensity ultracold neutron (UCN) source. Our target accuracy is an order-of-magnitude improvement over the current best experimental limit of the neutron EDM [1]. In the neutron EDM measurement, the Larmor precession frequency of UCNs stored in a cell under a magnetic and an electric fields is measured by Ramsey's technique of separately oscillating fields [2]. One of the essential steps of this measurement is polarization analysis of the UCNs, which is done by a polarization analyzer consisting of an iron thin film surrounded by a permanent magnet, and a UCN detector.

We are developing iron thin films for the polarization analyzer. They are required to have high saturation magnetizations and low coercivities. We produce ones with lower coercivities than those used in previous studies [3]. The advantages of them are that the leakage magnetic field can be reduced, and that the detector can be easily enlarged. We have characterized thin iron films produced by the ion beam sputtering facility [4] at the Institute of Combined Nuclear Science, Kyoto University, by neutron reflectivity measurements at J-PARC BL05 and vibrating sample magnetometry. In this talk, the results of these characterization measurements will be presented.

[1] C. Abel et al., Phys. Rev. Lett. 124, 081803 (2020).
[2] N. F. Ramsey, Phys. Rev. 78, 695 (1950).
[3] S. Afach et al., Eur Phys J. A 51, 143 (2015).
[4] M. Hino et al., Nucl. Inst. Meth. A 797, 265 (2015).

Joint GPD - Helicity session / 61

Longitudinal Spin Transfer to Lambda Hyperons in CLAS12

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Using the self analyzing decay of the Λ^0, the longitudinal spin transfer D_{LL} from a polarized electron beam scattering an unpolarized proton target to the hyperon can be measured. For Λ's produced in the current fragmentation region, this quantity is proportional to the helicity dependent fragmentation function G_1^Λ and can provide insight into the spin structure of the Λ^0. Currently, experimental data on D_{LL} is limited and is not able to discriminate between different models of the Λ^0 spin structure. This contribution will report the status of the ongoing analysis of the longitudinal spin transfer using data taken by the CLAS12 experiment at Jefferson Lab, a large acceptance spectrometer using

a 10.6 GeV electron beam. A focus of the analysis will be on the use of Graph Neural Networks (GNNs) to identify signal events.

Joint BSM - Lowenergy - Future Session US timezone / 62

The precision nEDM measurement with UltraCold Neutrons at TRIUMF

Authors: Ryohei Matsumiya[1]; TUCAN collaboration[None]

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The TRIUMF Ultra-Cold Advanced Neutron (TUCAN) collaboration aims at a precision neutron electric dipole moment (nEDM) measurement with an uncertainty of 10^{-27} e·cm, which is an order-of-magnitude better than the current nEDM upper limit [1] and enables us to test Supersymmetry. To achieve this precision, our collaboration has been developing a new high-intensity ultracold neutron (UCN) source and a nEDM spectrometer at TRIUMF, Canada.

Recent nEDM experiments are performed by measuring the Larmor precession frequency of polarized UCNs confined in a spin precession chamber where static magnetic and electric fields are applied. The spin precession of the UCNs in the chamber is observed by Ramsey's technique of separately oscillating magnetic field [2]. Our nEDM spectrometer polarizes UCNs with a 3.5 T magnetic field generated by a superconducting magnet, and then transports them through UCN guides to a spin precession chamber. The chamber is placed in a magnetically shielded room where the internal magnetic field is controlled with high precision Cs magnetometers and compensation coils. After flipping the UCN spin by Ramsey's technique, the UCNs are guided from the chamber to UCN detectors. The polarization of the UCNs is analyzed by counting the number of UCNs transmitting through magnetized iron thin films placed before the detectors.

We have been developing these sub-systems of the nEDM spectrometer. In this talk, the overview of our project and the current development status will be presented.

[1] C. Abel et al., Phys. Rev. Lett. 124, 081803 (2020).
[2] N. F. Ramsey, Phys. Rev. 78, 695 (1950).

Joint BSM - Lowenergy - Future Session US timezone / 63

Spin tune responce to vertical orbit correction at COSY

Author: Artem Saleev[1]

Co-authors: Joerg Pretz [2]; Vera Shmakova [3]; Paolo Lenisa [4]; Frank Rathmann [5]

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Searches of electric dipole moments (EDM) of charged particles
in pure magnetic rings, such as COSY, or electrostatic and hybrid

magnetic-electric storage rings, planned in the future, require new methods to disentangle the EDM signal from the large background produced by magnetic dipole moments. In these experiments, the sources of systematic background are in-plane magnetic fields. It is important to distinguish the origins of the in-plane magnetic fields, which could be produced intentionally by vertical orbit correction to keep the beam on a closed path, or unintentionally due to the alignment errors of the magnets. We propose to use the method of spin tune mapping to determine the relative importance of the two origins. At the first stage, the model of COSY should be verified for the spin tune shifts when vertical three-steerer closed-orbit bumps are applied. At the second stage, the spin tune responce to vertical orbit correction in the arcs will testify its contribution to the systematic background.

Transverse Momentum Structure (TMD) / 64

Transverse Spin Dependent Azimuthal Correlations of Charged Pion Pairs in $p^{\uparrow}p$ Collisions at $\sqrt{s} = 200$ GeV at STAR

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At the leading twist, the transversity distribution function, $h_1^q(x)$, where x is the longitudinal momentum fraction of the proton carried by quark q, encodes the transverse spin structure of the proton. Extraction of it is difficult because of its chiral-odd nature. However, it can be coupled to a spin-dependent interference fragmentation function, leading to experimentally measurable azimuthal correlations, A_{UT}, between the spin of the fragmenting quark and oppositely charged final state hadron pairs (di-hadron). The STAR experiment at RHIC has previously observed non-zero A_{UT} for $\pi^+\pi^-$ pairs using $p^{\uparrow}p$ collision data at $\sqrt{s} = 200$ GeV from 2006 and at $\sqrt{s} = 500$ GeV from 2011, corresponding to integrated luminosities, L, of 1.8 pb^{-1} and 25 pb^{-1}, respectively. In 2015, STAR collected $L \sim 52$ pb^{-1} of $p^{\uparrow}p$ collisions at $\sqrt{s} = 200$ GeV. This dataset provides highest precision A_{UT} measurement at $\sqrt{s} = 200$ GeV to date, which covers quark momentum fractions $0.1 < x < 0.4$, and is sensitive to valence quark $h_1^q(x)$. We will present preliminary results on A_{UT} for $\pi^+\pi^-$pairs based on this dataset.

Transverse Momentum Structure (TMD) / 65

Transverse polarization of hyperons in SIDIS from twist-3 gluon fragmentation functions

Author: Riku Ikarashi[1]

Co-authors: Yuji Koike [2]; Kenta Yabe [2]; Shinsuke Yoshida [3]

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We study the transverse polarization of hyperons produced
in semi-inclusive deep inelastic scattering, $ep \to e\Lambda^{\uparrow}X$,
in the collinear twist-3 factorization. This process receives three types of

twist-3 contributions: (i) twist-3 distribution in the initial proton combined with the transversity fragmentation function (FF) for the hyperon, (ii) Twist-3 quark FFs for the hyperon, and (iii) Twist-3 gluon FFs for the hyperon. In this talk, we present the twist-3 cross section for (iii) in the leading order (LO) with respect to the QCD coupling constant, which completes the LO cross section for this process. Since gluons are ample in the nucleons, this contribution representing multi-gluon correlations in the fragmentation process is potentially as important as other two contributions. This study is relevant for the future Electron-Ion Collider experiment.

Transverse Momentum Structure (TMD) / 66

Twist-3 gluon fragmentation contribution to hyperon polarization and its frame independence

Authors: Yuji Koike[1]; Kenta Yabe[1]; Shinsuke Yoshida[2]

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We discuss twist-3 gluon fragmentation function (FF) contribution to the polarized hyperon production in unpolarized pp collisions. The final formula for the LO cross section is presented. We emphasize the importance of the Lorentz invariance relations and the QCD equation-of-motion relations among the twist-3 gluon FFs to guarantee the frame independence of the twist-3 cross section. This study is relevant for the hyperon polarization measurement at RHIC.

Applications of Nuclear Polarization in other Fields / 67

Polarization REsearch for Fusion Experiments and Reactors - The PREFER collaboration: purposes and present status

Author: GIuseppe Ciullo[1]

Co-authors: M. Büscher [2]; Ralf Engels [3]; Marco La Cognata [4]; Peter Rakitzis [5]; Marco Statera [6]; D. K. Toporkov [7]; A. Vasilyev [8]

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[4] *infn-lns Catania*

[5] *FORTH-IESL and Crete University, Heraklion, Greece*

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The PREFER (Polarization REsearch for Fusion Experiments and Reactors) collaboration aims to address the know-hows in different fields and techniques to the challenging bet on fusion with polarized fuel.
The efforts on a variety of duties and goals, which are under the responsibility of different institutes and research groups (indicated here by the representatives of the research center groups in the author list).

Starting from still open questions of fusion reaction physics, as for example the study of d-d spin dependent cross sections (Vasilyev/La Cognata) to the acceleration of polarized ions from laser-induced plasmas (Büscher), there are many connections between the involved research groups. The collaboration is also tackling the production of nuclear polarized molecules, recombined from a polarized atomic beam (Engels), and its cryogenic condensation and transport (Ciullo/Statera).
Other options for the production of polarized fuel are investigated in parallel, like spin separation of molecules in polarized molecular beam sources (Toporkov) or via photodissociation of molecules into polarized hydrogen/deuterium atoms (Rakitzis).
The status of the different fields under investigation and the connections between these topics and the different research groups will be provided.

Acceleration, Storage and Polarimetry of polarized Beams / **68**

Simulations of Beam Dynamics and Beam Lifetime for the Prototype EDM Ring

Author: Andreas Lehrach[None]

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The matter-antimatter asymmetry may be explained through CP-violation by observing a permanent electric dipole moment (EDM) of subatomic particles. An advanced approach to measure the EDM of charged particles is to apply a unique method of "Frozen spin" on a polarized beam in an accelerator. To increase the experimental precision step by step and to study systematic effects, the EDM experiment can be performed within three stages: the magnetic ring COSY, a prototype EDM ring and finally all electric EDM ring. The intermediate ring will be a mock-up of the final ring, which will be used to study a variety of systematic effects and to implement the basic principle of the final ring. The simulations of beam dynamics of prototype EDM ring with different lattices are performed to optimize the beam lifetime and to minimize the systematic effects. The preliminary design of prototype EDM ring helped to estimate the beam losses by using analytical formulas. Further investigations on enhancing EDM measurement precision and reducing systematic effects are in process.

Transverse Momentum Structure (TMD) / **69**

Nuclear TMDs and 3D imaging in nuclei

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We perform the first simultaneous global QCD extraction of the transverse momentum dependent (TMD) parton distribution functions and the TMD fragmentation functions in nuclei. We have considered the world set of data from semi-inclusive electron-nucleus deep inelastic scattering and Drell-Yan di-lepton production. In total, this data set consists of 126 data points from HERMES, Fermilab, RHIC and LHC. Working at next-to-leading order and next-to-next-to-leading logarithmic accuracy, we achieve a $\chi^2/dof = 1.045$. In this analysis, we quantify the broadening of TMDs in nuclei comparing with those in free nucleons for the first time. We also make predictions for the ongoing JLab 12 GeV program and future EIC measurements.

Polarized Sources and Targets / 70

Optically polarized alkali metal cell for muonic helium measurements

Author: Takashi Ino[1]

Co-authors: Seiso Fukumura [2]; Patrick Strasser [3]; Masaki Fujita [4]; Yoichi Ikeda [4]; Sohtaro Kanda [3]; Masaaki Kitaguchi [5]; shoichiro Nishimura [3]; Takayuki Oku [6]; Takuya Okudaira [2]; Hirohiko Shimizu [2]; koichiro Shimomura [3]

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Muonic helium is a helium atom with one of the two electrons substituted by a negative muon. This three-body atomic system gives rise to opportunities to precisely study the hyperfine structure interval as well as the negative muon magnetic moment and mass. Muonic helium atoms are formed by stopping a negative muon beam in dense helium gas, but in this formation process, the polarization of muons is lost by a factor of ten or more, remaining only several percent of the muons spin-polarized. They can, however, be repolarized by spin-exchange collisions with polarized alkali metal atoms [1], the same as spin-exchange optical pumping often used to polarize noble gas nuclei [2].
We are studying glass cells containing pressurized helium gas and alkali metals for muonic helium measurements at J-PARC Muon Facility MUSE [3]. The glass cell, helium gas pressure, and polarized alkali metal density are essential to maximize the number of polarized muonic helium atoms. So called hybrid alkali metal optical pumping, which was first developed to achieve a high 3He nuclear polarization [4], can be applied for effective repolarization of muonic helium atoms. In the hybrid optical pumping, Rb is optically pumped conventionally, and the Rb polarization is rapidly passed to K atoms by spin-exchange collisions inside a cell with Rb and K enclosed together. Thanks to the smaller spin-destruction cross section in K-K collisions compared to those between Rb atoms, a higher alkali metal number density with a very high polarization can be obtained by the hybrid method.
We will discuss hybrid alkali metal optical pumping cells for muonic helium measurements.

[1] A. S. Barton et al., Phys. Rev. Lett. 70, 758 (1993).
[2] T. G. Walker and W. Happer, Rev. Mod. Phys. 69, 629 (1997); T. R. Gentile, P. J. Nacher, B. Saam, and T. G. Walker, Rev. Mod. Phys. 89, 045004 (2017).
[3] P. Strasser, K. Shimomura, and H. A. Torii, JPS Conf. Proc. 21, 011045 (2018).
[4] E. Babcock et al., Phys. Rev. Lett. 91, 123003 (2003).

Acceleration, Storage and Polarimetry of polarized Beams / 71

Beam-based alignment at the Cooler Synchrotron (COSY)

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The Jülich Electric Dipole moment Investigations (JEDI) collaboration is performing a measurement of the electric dipole moment (EDM) of charged hadrons in storage rings. To perform this measurement with a high precision, it requires a small systematic error. A large contribution to the systematic error is due to unknown magnetic fields, which are picked up when one is off of the optimal orbit. This effect can be reduced by controlling the orbit to a high precision to a small orbit root mean square (RMS) an thus preventing the pickup of these unknown magnetic fields.

In order to achieve a good orbit RMS in an accelerator, one needs to know the size of the offsets between the beam position monitors (BPMs) and the quadrupoles. These offsets can be determined with the use of the beam-based alignment method, which finds the magnetic center of a quadrupole with respect to the electric center of a BPM. When the offsets between the BPMs and quadrupoles are then known, one can re-calibrate the BPMs to have the zero orbit going through the magnetic centers of the quadrupoles. Thus, one prevents picking up extra magnetic fields, by going through the quadrupoles at a known, central, position instead of being at an off-center position.

The working principle of this method will be explained and the results of the beam-based alignment measurement done at the Cooler Synchrotron (COSY) will be shown.

Joint BSM - Accelerator - Future Session EU timezone / **72**

Spin-related measurements on charmed baryons at Belle

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Charmed baryons are actively studied in Belle experiment
and measurements on spin-related phenomena such as
weak decay asymmetries are obtained recently.
In this talk, we will report the determination of
$\Xi_c(2970)$ spin-parity and the measurements of
decay asymmetries in Ξ_c weak decays.
In addition, other results on charmed baryon will be
presented if time allows.

Joint GPD - Future session / **73**

Exclusive production of Quarkonia and Heavy Flavors to access gluon Generalized Parton Distributions at EIC

Authors: Tyler Schroeder[None]; Marie Boer[None]

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Exclusive heavy meson production is a key tool for accessing the inner dynamics of the proton. These reactions involve the proton Generalized Parton Distributions (GPDs), which correlate the longitudinal momenta and their transverse distribution of the proton's composite partons. The hard exclusive production of Quarkonia (J/ψ, Υ, etc.) is particularly interesting, as it accesses the gluon GPDs at the lowest order. We used ROOT to create a new flexible generator for the photoproduction, quasi-photoproduction, and electroproduction of vector mesons off a proton. The output phase space is weighted by the reaction cross-section, creating a realistic graph of event count as a function of kinematics. We will discuss the relevance of measuring hard exclusive production of Quarkonia, present our work on the event generator, and discuss our projections for the upcoming Electron-Ion Collider (EIC).

Fundamental Symmetries and and Spin Physics Beyond the Standard Model / 74

Nucleon EDM from polarized DIS

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I point out the connection between the matrix element of the CP-violating Weinberg operator and certain higher-twist corrections in polarized DIS. Based on this observation I estimate the induced nucleon EDM.

Nucleon Helicity Structure / 75

First Extraction of Polarized Sea Asymmetry from Weak Boson Production in Proton-Proton Collisions

Authors: Christopher Cocuzza[1]; Jake Ethier[2]; W. Melnitchouk[3]; Andreas Metz[1]; N. Sato[3]

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We present the first global QCD analysis of helicity parton distribution functions (PDFs) to include the latest polarized W-lepton production data from the STAR collaboration at the Relativistic Heavy-Ion Collider. This data allows the first extraction of a nonzero helicity light quark sea asymmetry within a global QCD analysis. By performing a simultaneous extraction of the unpolarized and helicity PDFs, we are also able to extract for the first time in a self-consistent manner the polarizations of the light sea quarks $\Delta\bar{u}/\bar{u}$ and $\Delta\bar{d}/\bar{d}$.

Joint TMD - GPD - HELCITY - Future session EU timezone / 76

The gT(x) contribution to single spin asymmetry in SIDIS

Authors: Sanjin Benic[None]; Yoshitaka Hatta[1]; Abhiram Kaushik[2]; Hsiang-nan Li[3]

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I will talk about our recent computation [1] of a gT(x) contribution to transverse single spin asymmetry (SSA) in SIDIS in a collinear framework. In [1] we have found that gT(x) first appears at two-loops. I will explain main steps of our calculation and show the final formula for the cross section [2] in the Wilczek-Wandzura (WW) approximation, that is, neglecting the genuine twist-3 pieces. In the WW approximation gT(x) is given as an integral of the helicity distribution, which is known from global fits. In this way, an explicit evaluation of SSA has no free parameters in principle. I will show our results from an extensive numerical computation for the spin dependent moments A_UT, such as

Sivers and Collins moment, coming from gT [2], for the future EIC kinematics. Finally, I will make comments about an analogue contribution in the gluon initiated channel arising from the G_3T(x) that is also included in our full numerical setup.

[1] S. B., Y. Hatta, H-n. Li, D.-J. Yang, Phys. Rev. D 100 (2019) 9, 094027
[2] S. B., Y. Hatta, A. Kaushik, H.-n. Li, in preparation

Joint GPD - Helicity session / **77**

transverse spin sum rules

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There are two transverse spin sum rules for the proton: One involves twist-2 GPDs, which has a partonic interpretation, and the other involves twist-3 distributions including the well-know spin structure function g_2. I will explain the origin and physics of these two spin sum rules.

Polarized Sources and Targets / **78**

New application of a Sona transition unit: Observation of direct transitions between quantum states with energy differences of 10 neV and below

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For more than 50 years Sona transition units have been used at polarized sources to exchange the occupation numbers between 'pure' hyperfine substates. For instance, hydrogen atoms in the hyperfine substate $|F = 1, m_F = +1\rangle$ are transferred into $|F = 1, m_F = -1\rangle$ when these atoms are passing a static magnetic field gradient between two opposing solenoidal magnetic fields. Thus, the magnetic field direction, i.e. the quantization axis, is rotated faster than the spin orientation can follow due to the Larmor precession.
In parallel, the atoms traveling through the zero crossing of the static magnetic field experience in their rest frame an oscillating magnetic field. This oscillation is equivalent to an external radio frequency field of frequency $f = v_{atom}/\lambda$ that can induce transitions between hyperfine substates with the energy difference $\Delta E = h \cdot n \cdot f$, where n is an integer. Here, the distance between the opposite coils determines the wavelength λ, thus the beam velocity v_{atom} can be used to manipulate the frequency f to induce transitions between quantum states with energy differences of 10 neV and below. These tiny energy differences can be found between hyperfine substates of hydrogen atoms at low magnetic fields in the Breit-Rabi diagram. In this talk first measurements, their interpretation and possible applications will be presented.

Fundamental Symmetries and and Spin Physics Beyond the Standard Model / 79

The search for electric dipole moments of charged particles using storage rings

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One of the major problems of modern particle physics is the inability of the Standard Model (SM) of Particle Physics to explain the matter-antimatter asymmetry in the Universe. Therefore, the pursuit of physics beyond the SM is required and one of the necessary conditions for the appearance of the matter-antimatter asymmetry is the violation of the CP symmetry. Permanent electric dipole moments (EDMs) of particles violate both time reversal and parity invariance and, via the CPT-theorem they also violate the combined CP symmetry. Hence, EDM measurements of fundamental particles are capable to probe new sources of CP-violation.

Storage rings provides possibility to measure EDMs of charged particles by observing the effect of the EDM on the spin motion in the ring. The Cooler Synchrotron COSY at the Forschungszentrum Jülich provides polarized protons and deuterons with momenta up to 3.7 GeV/s, which is an ideal testing ground and starting point for the JEDI collaboration (Jülich Electric Dipole moment Investigations) for such an experimental program.

The talk will present recent results of the first direct (precursor) measurements of the deuteron EDM in COSY.

Joint TMD - GPD - HELCITY - Future session US timezone / 80

Back-to-back proton-pi+ correlations with CLAS12

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We report preliminary results from the first measurement of a novel beam-spin asymmetry involving the back-to-back production of a target-fragmentation proton and current-fragmentation π^+. Non-zero $\sin\Delta\phi$ moments for the semi-inclusive deep inelastic scattering process, $ep \rightarrow P\pi^+X$, where the $\Delta\phi$ is the difference of azimuthal angles between the two hadrons, indicate that spin-orbit correlations between target and current fragments may be significant. The dependence of the modulation on the product of transverse momenta of two hadrons is consistent with predictions based on the fracture function formalism. Data was taken with the upgraded CLAS12 detector at Jefferson Lab where a 10~GeV electron was scattered off of a liquid hydrogen target during two run periods in 2018 and 2019.

Acceleration, Storage and Polarimetry of polarized Beams / 81

Spin Transparency Method for High Precision Experiments with Polarized Beams

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The Spin Transparency technique is discussed as an efficient, highly flexible method for control of the beam polarization. It applies from acceleration to long term maintenance and spin manipulation in real time during an experimental run of a collider or storage ring. This method relies on "transparent" collider structures where, for a particle moving on the design orbit, any initial orientation of its spin is repeated every turn at any location along the orbit. Precision control of the spin direction and the spin tune is accomplished using "spin navigators" based on weak longitudinal and transverse magnetic fields. Spin navigators can be used to compensate the effects of field errors as well as to reverse the spins multiple times during an experiment. This allows one to substantially reduce the experiment's systematic errors and reach a new level of measurement precision. The main features of the spin transparency mode are demonstrated using the examples of a figure-8 collider, a racetrack with two identical Siberian snakes, as well as a conventional ring at an energy corresponding to an integer spin resonance. We demonstrate the feasibility of low-energy figure-8-based rings dedicated to search for Electric Dipole Moment and Dark Matter. We consider the possibility of applying the spin transparency mode at ultra-high energies.

Future facilities and experiments / **82**

Neutron Spin Structure from e-3He Scattering with Double Spectator Tagging at the Electron-Ion Collider

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This spin structure function of the neutron is traditionally determined by measuring the spin asymmetry of inclusive electron deep-inelastic scattering (DIS) off polarized ^{3}He nuclei. In such experiments, correcting for nuclear effects can introduce large systematic uncertainties and model-dependencies. This talk presents our study of the feasibility of suppressing such model dependencies by tagging both spectator protons in the process of DIS off neutrons in ^{3}He at the forthcoming Electron-Ion Collider (EIC). This allows us to reconstruct the momentum of the struck neutron to ensure it was nearly on-shell in the initial state, thereby reducing sensitivity to nuclear corrections, and to suppress contributions from electron DIS off protons in ^{3}He. We find that the EIC can probe the neutron spin structure from x_B of 0.003 to 0.0651. We further find that the double spectator tagging method results in reduced uncertainties by a factor of 4 on the extracted neutron spin asymmetries over all kinematics, and by a factor of 10 in the low-x_B region, providing high-precision data that will give insight into the spin structure of the nucleon.

Nucleon Helicity Structure / **83**

Studies of Neutral Current Neutrino-Nucleon Scattering with the MicroBooNE Detector

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The MicroBooNE experiment is an 85 ton active volume liquid-argon time projection chamber (LArTPC) located in the Booster Neutrino Beamline at Fermilab. The excellent calorimetric and spatial resolution of the LArTPC allows us to identify isolated proton tracks with lengths as short as 2 cm, which is equivalent to proton kinetic energy T = 50 MeV. We report the progress towards the first measurement of muon neutrino neutral current elastic scattering from protons in Argon in the region of four-momentum transfer squared, $0.1 < Q^2 < 1$ GeV^2, using MicroBooNE's 6.87×10^{20} POT data. We also present our plan to extract the strange quark contribution to the axial form factor, which is crucial for understanding the strange quark contribution to the proton spin.

Transverse Momentum Structure (TMD) / 84

Polarized Drell-Yan experiment at Fermilab, SpinQuest (E1039)

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E1039/SpinQuest is a polarized fixed-target Drell-Yan experiment using the 120 GeV proton beam from the Main Injector at Fermilab. The primary goal of SpinQuest is to measure the Sivers asymmetries, aiming to shed light on the fundamental question, "Do the light sea quarks contribute to the intrinsic spin of the nucleon via their orbital angular momentum?". The Sivers asymmetry was first introduced to explain the unexpected, significant, transverse, single-spin asymmetries observed in the hadron-scattering. The Sivers functions for u and d quarks have been measured and found to be similar in size but with the opposite sign, but there are no data available yet for the sea quarks Sivers functions. SpinQuest will determine the $\bar{u}$ and $\bar{d}$ Sivers asymmetries in Drell-Yan using the transversely polarized proton and deuteron targets for the first time. The overview of SpinQuest, including the recent progress toward physics data taking, will be presented.

Polarized Sources and Targets / 85

Dilution factor calculation and its contribution to SpinQuest systematic error

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The spin of the nucleon is well established but the contribution to this intrinsic value from its constituent partons is still under intense investigation. As part of a global effort to map out these individual contributions, the SpinQuest experiment at Fermilab aims to add significantly to the level of information available on sea-quarks by measuring their Sivers function. To separate the contributions of u bar and d bar quarks to the Sivers asymmetry, the experiment uses both NH3 and ND3 polarized targets, interacting with an incoming unpolarized 120 GeV/c proton beam. The dimuons from the Drell-Yan process are detected to analyze the azimuthal asymmetry. The incoming proton beam will also interact with other materials that are present in the experimental beam path, such as the target cell walls, the aluminum insert ladder, the microwave horn, liquid helium and nitrogen in the ammonia target. The figure of merit in our extracted Sivers function is directly dependent on both the magnitude of polarization and the interaction rate from these various unwanted materials resulting in a dilution factor. With the use of MCFM (Monte Carlo simulation at femtobarn), a par- ton distribution based cross-section generator we can analyze the contributions from unmeasured cross-section from these various materials to find the degree of dilution and the corresponding

kinematic sensitivity. This contribution to the experimental systematic error and its management is reviewed in this presentation.

Plenary Presentations / 86

Dipole polarizability from small-angle proton scattering and implications for symmetry energy properties and the formation of neutron skins

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The dipole polarizability of nuclei carries information on the density dependence of the symmetry energy governing the properties of the Equation of State of neutron-rich matter relevant to neutron stars and core-collapse supernovae. In recent years, zero-degree polarized proton scattering has been developed at RCNP as an experimental tool to measure the dipole polarizability [1]. Such data also provide constraints on the neutron skin thickness of heavy nuclei [2]. A recent study of ^{40}Ca together with results from a previous experiment on ^{48}Ca [3] serve as a test of state-of-the-art ab initio [4,5] and energy densitiy functional [6] calculations. From the good agreement obtained for both methods one can set limits on the density dependence of the symmetry energy. These are clearly at variance with those derived [7] from the recently published result of the PREX-II experiment [8].

[1] P. von Neumann-Cosel and A. Tamii, Eur. Phys. J. A 55, 110 (2019).
[2] A. Tamii et al., Phys. Rev. Lett. 107, 262502 (2011).
[3] J. Birkhan et al., Phys. Rev. Lett. 118, 252501 (2017).
[4] J. Simonis, S. Bacca, and G. Hagen, Eur. Phys. J. A 55, 241 (2019).
[5] S. Kaufmann et al., Phys. Rev. Lett. 124, 132502 (2020).
[6] P.-G. Reinhard, X. Roca-Maza, and W. Nazarewicz, arXiv:2105.15050.
[7] B.T. Reed, F.J. Fattoyev, C.J. Horowitz, and J. Piekarewicz, Phys. Rev. Lett. 126, 172503 (2021).
[8] D. Adhikari et al., Phys. Rev. Lett. 126, 172502 (2021).

Joint TMD - GPD - HELCITY - Future session US timezone / 87

Global Analysis of SSAs and the Impact of the EIC on Tensor Charge Extractions

Authors: Alexei Prokudin[None]; Daniel Pitonyak[None]; Leonard Gamberg[None]; Nobuo Sato[None]; Ralf Seidl[1]; Zhongbo Kang[None]

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We perform the first simultaneous QCD global analysis of data from semi-inclusive deep inelastic scattering, Drell-Yan, e+e- annihilation into hadron pairs, and proton-proton collisions. Consequently, we are able to extract a universal set of nonperturbative functions that describes the observed asymmetries in these reactions. The outcome of our analysis indicates single transverse-spin asymmetries in high-energy collisions have a common origin. We study the impact of the Electron-Ion Collider (EIC) on the phenomenological extraction of the tensor charge from a QCD global analysis of single transverse-spin asymmetries (SSAs). We generate EIC pseudo-data for the Collins effect in semi-inclusive deep-inelastic scattering for proton and H3e beams across multiple center-of-mass energies. We find a significant reduction in the uncertainties for the up, down, and

isovector tensor charges that will make their extraction from EIC data on SSAs as precise as current lattice QCD calculations. We also analyze the constraints placed by future data from the proposed SoLID experiment at Jefferson Lab, discuss its important complementary role to the EIC, and present the combined impact from both facilities.

Nucleon Helicity Structure / 88

Collinear twist-3 approach to hyperon polarization in SIDIS

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We discuss the production of transversely polarized hyperons in semi-inclusive deep inelastic scattering in the framework of the collinear twist-3 factorization. In this framework, the twist-3 cross section consists of three contributions depending on the origins for the polarizations: (i) Twist-3 distribution in the initial proton combined with the twist-2 transversity fragmentation function (FF) for the final hyperon, (ii) Twist-3 quark FF for the hyperon and (iii) Twist-3 gluon FF for the hyperon. In this talk. we focus on the first two contributions, since they are expected to become dominant contribution. We present the twist-3 cross section in the leading order (LO) with respect to the QCD coupling constant for all the five structure functions which have different dependences on the azimuthal angles. We also discuss the matching with the TMD framework in the small-P_T region. The present result is important for the future EIC experiment.

Fundamental Symmetries and and Spin Physics Beyond the Standard Model / 89

Towards a surrogate computational tool to quantify the systematic uncertainties in EDM experiments in storage rings

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The searches for permanent Electric Dipole Moments (EDMs) of elementary particles provide a powerful tool to probe physics beyond the standard model (SM). This is particularly useful to investigate the CP-violation mechanisms that can explain the matter-antimatter asymmetry in the universe.
Conducting such searches in storage rings requires unprecedented understanding of beam and spin dynamics, dictated by the smallness of the EDM signal to be measured. Given the complexity of storage rings, the desired signal is mainly dominated by the systematic uncertainties of the machine. It is therefore mandatory to build a computational model that emulates the realistic machine in order to help to disentangle the real signal out of the fake one.
This talk will present a surrogate computational tool in the context of spin and beam dynamics, to quantify the hierarchy of uncertainties in a storage ring. This tool will be applied to a model of the Cooler Synchrotron (COSY) as a proof-of-principle.

Joint TMD - GPD - HELCITY - Future session US timezone / 90

Time-reversal Odd Side of a Jet

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We re-examine the jet probes of the nucleon spin and flavor structures. We find for the first time that the time-reversal odd (T-odd) component of a jet, conventionally thought to vanish, can survive due to the nonperturbative fragmentation and hadronization effects. This additional contribution of a jet will lead to novel jet phenomena relevant for unlocking the access to several spin structures of the nucleon, which were thought to be impossible by using jets. As examples, we show how the T-odd constituent can couple to the proton transversity at the Electron Ion Collider (EIC) and can give rise to the anisotropy in the jet production in e+ e– annihilations. We expect the T-odd contribution of the jet to have broad applications in high energy nuclear physics.

Nucleon Helicity Structure / 91

Small-x Helicity Evolution and the Proton Spin Puzzle

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We report on the first phenomenological analysis of the world polarized deep-inelastic scattering (DIS) data incorporating small-x helicity (Kovchegov-Pitonyak-Sievert) evolution. This framework allows for one to predict the behavior of helicity parton distribution functions (PDFs) down to very low x. Consequently, one can control the uncertainties in these functions beyond the measured region and make precise calculations of the integrals needed to determine the contribution of quark and gluon spin to the proton spin. Therefore, the small-x helicity formalism will play a crucial role in using future Electron-Ion Collider data to resolve the proton spin puzzle.

Transverse Momentum Structure (TMD) / 92

Transverse single-spin asymmetries of W±-bosons in p+p collisions at √s = 510 GeV

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The STAR experiment at RHIC has measured transverse single-spin asymmetries of W±-bosons in proton-proton collisions at a center-of-mass energy √s = 510 GeV (2017 data). These asymmetries

probe correlations between parton motion and the proton spin in the initial state which are described in terms of transverse momentum dependent parton distribution functions (TMD), in this case the Sivers function. The Sivers function is of particular theoretical interest because its process dependence can be linked to underlying kinematics, namely the gauge link structure of the scattered parton with the nucleon remnant. This means that the Sivers function is not universal and a sign change is expected between the asymmetries measured in semi-inclusive deep inelastic scattering compared to those in hadronic collisions. The new STAR preliminary results with an integrated luminosity of about 350 pb^{-1} improve significantly on previous data from 2011. We will discuss details of the full reconstruction of the W-boson kinematics which are required for a true TMD measurement. Comparison with recent global fits will illustrate the potential impact of the new data.

Joint BSM - Lowenergy - Future Session US timezone / 93

Evolution of primordial neutrino helicities in cosmic magnetic fields and gravitational inhomogeneities

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Primordial neutrinos decoupled in the early universe predominantly in helicity eigenstates. Their subsequent propagation through the residual cosmic and galactic magnetic fields partially flips their helicities.[1] In view of the possibility of large neutrino magnetic moments arising from beyond-the-standard-model physics – e.g., as the XENON1T experiment reported as a possible explanation of their low energy event excess – we estimate the magnitudes of the helicity flips for relic Dirac neutrinos both in galactic and cosmic magnetic fields. Majorana neutrinos would not undergo such flips. The helicity flip probability is sensitive not only to the magnetic moment of neutrinos but also to the properties of galactic and cosmic fields, and thus can thus potentially probe astrophysical magnetic fields. We find that even a moment several orders of magnitude smaller than that possibly found by XENON1T could lead to significant helicity changes of Dirac neutrinos as they propagate to detectors on Earth. We also discuss the effects of gravitational inhomogeneities on the helicity of primordial neutrinos.[2]

[1] G. Baym and J. C. Peng, Phys. Rev. Lett. 126, 191803 (2021).
[2] G. Baym and J. C. Peng, Phys. Rev. D 103, 123019 (2021).

Joint BSM - Lowenergy - Future Session US timezone / 94

Primordial neutrino helicity modification in magnetic and gravitational fields and implications for their detection

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The evolution of primordial neutrino helicities in cosmic magnetic fields and gravitational inhomogeneity has been studied recently [1,2]. Detection of relic neutrinos from the Big Bang, e.g., through the inverse tritium beta decay reaction (ITBD) in the PTOLEMY experiment, remains a major challenge. We examine the implications of the helicity properties of the relic neutrinos on their detection in ITBD. While the ITBD rate is insensitive to the helicity of Majorana neutrinos, helicity flips of

Dirac neutrinos both via interactions with gravitational perturbations and cosmic and galactic magnetic fields does effect the ITBD detection rate for neutrino masses below $\sim 10^{-2}$ eV. However, resolving relic neutrino events from the tritium beta decay background becomes increasingly difficult with lower neutrino mass, and will require advances in electron detection techniques. We also discuss the prospect for detecting the ITBD reaction for the first time using an intense ^{51}Cr neutrino source.

1) G. Baym and J. C. Peng, Phys. Rev. Lett. 126, 191803 (2021).
2) G. Baym and J. C. Peng, Phys. Rev. D 103, 123019 (2021).

Transverse Momentum Structure (TMD) / 95

Gluon TMDs and J/ψ polarization in SIDIS

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We study the polarization of ⊠/⊠ mesons produced in semi-inclusive, deep-inelastic electron-proton scattering in different reference frames at the EIC energies. At low transverse momentum, we propose factorized expressions in terms of transverse momentum dependent gluon distributions and shape functions. In particular, we show that the distribution of linearly polarized gluons can, in principle, affect the polarization of the produced quarkonium states. We also demonstrate that our formulae, at the order ⊠⊠, correctly match with the collinear factorization results at high transverse momentum.

Form Factors and GPDs / 96

Accessing pion's large-x gluon by fixed-target charmonium production

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The pion, as the Goldstone boson of dynamical chiral symmetry breaking of the strong interaction, is the lightest QCD bound state. Because of its light mass, pion plays a dominant role in the long-range nucleon-nucleon interaction. Understanding the pion's internal structure is important to investigate the low-energy, non-perturbative aspects of QCD. Nevertheless, the uncertainties of partonic density functions (PDFs) of pions are relatively huge due to lacking rest pion targets.

In this talk, we will review recent theoretical and experimental progress of extracting the pion PDFs. Furthermore, we will provide quantitative evidence within the CEM and NRQCD frameworks that the existing pion-induced fixed-target J/psi data, are sensitive to the gluon density of pions, and favor the pion PDFs with relatively large gluon contents at large x.

References
[1] C.Y. Hsieh, Y.S. Lian, W.C. Chang, J.C. Peng, S. Platchkov, and T. Sawada, Chin. J. Phys. 73, 13 (2021); arXiv:2103.11660.

[2] W.C. Chang, J.C. Peng, S. Platchkov, and T. Sawada, Phys. Rev. D 102, 054024 (2020).Rev. D 99, 014032 (2019); arXiv:2006.06947.

Transverse Momentum Structure (TMD) / 97

TMDs for spin-1 hadrons

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We explain possible transverse-momentum-dependent parton distribution functions (TMDs) for spin-1 hadrons up to twist 4 by decomposing a quark correlation function with the conditions of the Hermiticity and parity invariance [1]. In the TMDs, there exist time-reversal-odd functions in addition to the time-reversal-even ones. We showed that 40 TMDs exist in the tensor-polarized spin-1 hadron in the twist 2, 3, and 4. In particular, we found 30 new structure functions in the twist 3 and 4 in our work. Since time-reversal-odd terms of the collinear correlation function should vanish after integrals over the partonic transverse momentum, we obtain new sum rules for the time-reversal-odd structure functions, $\int d^2k_T g_{LT} = \int d^2k_T h_{LL} = \int d^2k_T h_{3LL} = 0$. In addition, we indicated that new transverse-momentum-dependent fragmentation functions exist in tensor-polarized spin-1 hadrons. The tensor structure functions may not be easily measured in experiments. However, high-intensity facility such as the Thomas Jefferson National Accelerator Facility (JLab), the Fermilab Main Injector, and future accelerators like electron-ion collider (EIC) may probe such observables. In addition, since the Nuclotron-based Ion Collider fAcility (NICA) focuses on spin-1 deuteron structure functions, there is a possibility to study the details of polarized structure functions of the deuteron at this facility.

[1] S. Kumano and Qin-Tao Song, Phys. Rev. D 103 (2021) 014025.

Nucleon Helicity Structure / 98

Measurement of the anti-quark flavor asymmetry in the proton at FNAL-SeaQuest

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The flavor asymmetry of the unpolarized distributions of light anti-quarks (i.e. $\bar{u}(x)$ and $\bar{d}(x)$) in the proton was observed by several deep-inelastic muon scattering experiments. The ratio $\bar{d}(x)/\bar{u}(x)$ was measured by Drell-Yan experiments NA51 at CERN and E866 at Fermilab and a large asymmetry was reported.

The mechanism of this asymmetry has been studied via various theoretical models. The asymmetry of unpolarized distributions can be correlated with that of helicity distributions, e.g. the statistical model predicts the similar magnitude with the opposite sign; $\bar{d}(x) - \bar{u}(x) \approx -\left(\Delta\bar{d}(x) - \Delta\bar{u}(x)\right)$. Therefore a comparison between the unpolarized and helicity distributions of the sea quarks is appropriate.

SeaQuest at Fermilab is a fixed-target experiment designed to detect the Drell-Yan process in $p + p$ and $p + d$ reactions. The goal is to measure precisely the ratio $\bar{d}(x)/\bar{u}(x)$ in a wide Bjorken x region up to 0.45. Results from SeaQuest on the anti-quark flavor asymmetry will be presented.

Nucleon Helicity Structure / **99**

Constraining the Polarized Gluon Distribution Function of the Proton with Recent STAR Measurements

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The contribution of the gluon spin to the spin of the proton is being studied through the use of the unique capability of the Relativistic Heavy Ion Collider (RHIC) to collide longitudinally polarized protons at $\sqrt{s} = 200\,\text{GeV}$ and $\sqrt{s} = 510\,\text{GeV}$. The kinematic coverage of the Solenoidal Tracker At RHIC (STAR) allows access to gluons through quark-gluon and gluon-gluon scattering processes which dominate particle production at low and medium transverse momentum. The polarized gluon distribution function, $\Delta g(x)$, can be constrained through global analyses of the longitudinal double-spin asymmetries (A_{LL}) of inclusive jet and di-jet production.

Published inclusive jet results from 2009 data at mid-rapidity ($|\eta| < 1$) at $\sqrt{s} = 200\,\text{GeV}$ have been included in global analyses and suggest a significant non-zero truncated first moment of $\Delta g(x)$ for $x > 0.05$. An additional data sample of $43\,\text{pb}^{-1}$ has been collected in 2015 at the same collision energy. This new data sample is over twice as large as the previous sample, providing an opportunity to improve the precision of $\Delta g(x)$ for $x > 0.05$. The published results from the analysis of the 2015 data will be presented along with the status of the analysis using a large data sample of $250\,\text{pb}^{-1}$ collected at $\sqrt{s} = 510\,\text{GeV}$ in 2013.

Plenary Presentations / **100**

The physics program at EIC: towards the realization

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The Electron-Ion Collider (EIC) will be the new, most sophisticated accelerator facility for studying properties of nuclear matter at high intensity and resolving power. Nearly two decades in the planning, the EIC is now the highest priority project for new construction in the US Nuclear Physics Long Range Plan of 2015. It is enthusiastically endorsed by the US National Academy of Sciences in 2018. The EIC will address fundamental open questions on nucleon and nuclear structure, the origin of mass and nucleon spin, and the emergent properties of a dense system of gluons in nuclear matter.

To further sharpen and broaden the physics case and to evaluate experimental requirements for the detector design capable of delivering the EIC physics goal, the EIC Users Group has organized the Yellow Report Initiative. This intensive year-long study of planned physics measurements and required and available detector technologies resulted in the most comprehensive report, providing the basis for further development of experimental setup best suited for science needs.

In this talk, I will summarize the established EIC design capabilities and physics goals and then focus on recent progress in developments of physics measurement, corresponding experimental equipment requirements, and emerging detector concepts on the path for the realization of the EIC.

Polarized Sources and Targets / 101

Status of Lamb-shift polarized ion source at 6 MV tandem accelerator in UTTAC and its application to nuclear physics

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A polarized ion source has contributed to the development of the nuclear physics, as represented by the measurement of analyzing power. At University of Tsukuba Tandem Accelerator Complex (UTTAC), a Lamb-shift polarized ion source (PIS) is operated as one of the injections of 6 MV tandem accelerator. The PIS can produce highly negative polarized proton and deuteron beams. The PIS was damaged seriously ten years ago due to the Great East Japan Earthquake, but was recovered successfully within five years. Currently, the polarized proton and deuteron beams which are accelerated up to 12 MeV can be transported to the experimental course with approximately 100 nA and 10 nA for proton and deuteron beams, respectively. One of application to nuclear physics is the production of polarized unstable nuclei via polarization transfer reactions with polarized proton or deuteron beams. Up to now, we succeeded to produce polarized unstable nuclei for ^{25}Al (J = 5/2+, T1/2 = 7.183 s) and ^{29}P (J = 1/2+, T1/2 = 4.142 s). In addition, we observed nuclear magnetic resonances (NMR's) of them with the beta-ray detected NMR technique. In this presentation, we will talk about the current status of the PIS and experimental results related to the PIS.

Nucleon Helicity Structure / 102

Useful relations and sum rules for PDFs and multiparton distribution functions of spin-1 hadrons

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Sum rules for structure functions and their twist-2 relations have important roles in constraining their magnitudes and x dependencies and in studying higher-twist effects. The Wandzura-Wilczek (WW) relation and the Burkhardt-Cottingham (BC) sum rule are such examples for the polarized structure functions g_1 and g_2. Recently, new twist-3 and twist-4 parton distribution functions were proposed for spin-1 hadrons, so that it became possible to investigate spin-1 structure functions including higher-twist ones. We show in this work that an analogous twist-2 relation and a sum rule exist for the tensor-polarized parton distribution functions f_{1LL} and f_{LT}, where f_{1LL} is a twist-2 function and f_{LT} is a twist-3 one. Namely, the twist-2 part of f_{LT} is expressed by an integral of f_{1LL} (or b_1) and the integral of the function $f_{2LT} = (2/3)f_{LT} - f_{1LL}$ over x vanishes. If the parton-model sum rule for f_{1LL} (b_1) is applied by assuming vanishing tensor-polarized antiquark distributions, another sum rule also exists for f_{LT} itself. These relations should be valuable for studying tensor-polarized distribution functions of spin-1 hadrons and for separating twist-2 components from higher-twist terms, as the WW relation and BC sum rule have been used for investigating x

dependence and higher-twist effects in g_2. In deriving these relations, we indicate that four twist-3 multiparton distribution functions F_{LT}, G_{LT}, $H_{LL}^{\perp}$, and H_{TT} exist for tensor-polarized spin-1 hadrons. These multiparton distribution functions are also interesting to probe multiparton correlations in spin-1 hadrons.

Acceleration, Storage and Polarimetry of polarized Beams / **103**

High Precision 5 MeV Mott Polarimeter

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We report on the design and performance of a Mott polarimeter optimized for a nominal 5-MeV electron beam from the Continuous Electron Beam Accelerator Facility (CEBAF) injector. The rf time structure of this beam allows the use of time of flight in the scattered electron detection, making it possible to cleanly isolate those detected electrons that originate from the scattering foil, and resulting in measured scattering asymmetries which are exceptionally stable over a broad range of beam conditions, beam currents, and foil thicknesses. In two separate series of measurements from two different photocathode electron sources, we have measured the Mott scattering asymmetries produced by an approximately 86% transversely polarized electron beam incident on ten gold foils with nominal thicknesses between 50 and 1000 nm. The statistical uncertainty of the measured asymmetry from each foil is below 0.25%. Within this statistical precision, the measured asymmetry was unaffected by ±1-mm shifts in the beam position on the target foil, and by beam current changes and dead-time effects over a wide range of beam currents. The overall uncertainty of our beam polarization measurement, arising from the uncertainty in the value of the scattering asymmetry at zero foil thickness as determined from our fits to the measured asymmetries versus scattering foil thicknesses, the estimated systematic effects, and the (dominant) uncertainty from the calculation of the theoretical Sherman function, is 0.61%. A simulation of the polarimeter using GEANT4 has confirmed that double scattering in the target foil is the sole source of the dependence of the measured asymmetry on foil thickness, and gives a result for the asymmetry versus foil thickness in good agreement with both our measurements and a simple calculation. Future measurements at different beam energies and with target foils of different atomic numbers to bound uncertainties from small effects such as radiative corrections to the calculation of the polarimeter analyzing power will also be discussed.

"High precision 5 MeV Mott polarimeter", J. M. Grames, C. K. Sinclair, M. Poelker, X. Roca-Maza, M. L. Stutzman, R. Suleiman, Md. A. Mamun, M. McHugh, D. Moser, J. Hansknecht, B. Moffit, and T. J. Gay, Phys. Rev. C 102, 015501 – Published 6 July 2020

Transverse Momentum Structure (TMD) / **104**

Measurement of transverse single-spin asymmetries for dijet production in polarized p+p collisions at \sqrt{s} = 200 GeV at STAR

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We report a new measurement of transverse single-spin asymmetries for pair-production of jets in collisions of transversely polarized protons at $\sqrt{s}$ = 200 GeV with data taken in 2012 and 2015 at STAR. In this measurement we probe, at high Q^2, correlations between the transverse spin ($\vec{S}$) of a proton, moving in the longitudinal ($\vec{p}$) direction, and the transverse momenta of partons ($\vec{k}_T$) within the proton. A non-zero correlation – the Sivers effect – results in a spin-dependent shift in the dijet azimuthal opening angle away from 180°. The corresponding $\langle k_T \rangle$ is then calculated based on a simple kinematic model. By using charge-tagging of the jets to enhance either u- or d-quark contributions, we see a non-zero Sivers effect for the first time in dijet production in high-energy proton collisions. The individual parton contributions (u, d, gluon+sea) to the measured $\langle k_T \rangle$ are extracted through a matrix inversion of the charge-sorted $\langle k_T \rangle$ data. Preliminary results and status of the analysis will be presented.

Plenary Presentations / 105

Progress on fragmentation-function studies

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In recent years, significant progress has been made in improving our understanding of the QCD fragmentation process. I will review theoretical and experimental advances that can shed new light on both collinear and Transverse Momentum Dependent (TMD) fragmentation. Examples include new extractions of fragmentation functions, hadron-in-jet fragmentation, and multi-differential measurements. In addition, I will review spin-polarized observables in electron-positron annihilation, proton-proton collisions and at the future Electron-Ion Collider.

Transverse Momentum Structure (TMD) / 106

Transverse Single-Spin Asymmetries for π^0 and Electromagnetic Jets at Forward Rapidities in $p^{\uparrow}$+p Collisions at Center-of-Mass Energies of 200 GeV and 500 GeV at STAR

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There have been numerous attempts, both experimentally and theoretically, to understand the origin of the unexpectedly large transverse single-spin asymmetries (A_N) for inclusive hadron production at forward rapidity in $p^{\uparrow}$+p collisions that persist from low to high center-of-mass energies. Two proposed potential sources are the twist-3 contributions in the collinear factorization and the transverse-momentum-dependent contributions from either the initial-state quark and gluon Sivers functions or the final-state Collins fragmentation function. To investigate the underlying physics leading to this large A_N, we study π^0 A_N with different topologies – isolated and non-isolated, and A_N for electromagnetic jets (EM-jets) of different substructures using Forward Meson Spectrometer (FMS) detector at STAR. Jet A_N is sensitive to the initial state effect and can provide access to Sivers functions. To investigate final-state effects, we measure the Collins asymmetry of π^0 inside EM-jets. We present the most recent results for these asymmetries from $p^{\uparrow}$+p collisions at 200 GeV and 500

GeV. We also present new preliminary results of A_N for EM-jets in FMS and Endcap Electromagnetic Calorimeter (EEMC) using p$^{\uparrow}$+p collisions at 200 GeV where we explore the dependences of A_N on photon multiplicity inside the jet, jet transverse momentum, and jet energy. These results provide rich information towards understanding the physics mechanism of large A_N in hadron collisions.

Transverse Momentum Structure (TMD) / 107

General helicity formalism for two-hadron production in e^+e^- collisions and the Λ polarizing fragmentation function

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We present the complete structure of the azimuthal dependences and polarization observables for two-hadron production in e^+e^- annihilation processes within a TMD approach adopting the helicity formalism. The leading-twist quark and gluon TMD fragmentation functions (FFs) for spin-1/2 hadrons, with their properties and their probabilistic interpretation, are fully accounted for.
The role of the polarizing FF is discussed in detail and its extraction from Belle data for the transverse polarization of Λ's is shown. Predictions for SIDIS processes at EIC are presented.

Plenary Presentations / 108

Experimental studies on the high-energy spin physics in collider experiments at RHIC

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The Relativistic Heavy Ion Collider (RHIC) is the world's only polarized proton+proton collider, capable of reaching center of mass energies up to 510 GeV. RHIC's experiments, PHENIX and STAR, have been carrying out a cold QCD program in order to gain deeper insight into the proton's spin structure and dynamics.
Data from longitudinally polarized $p + p$ collisions allow one to study the gluon helicity distribution function ($\Delta g(x)$), by measuring the longitudinal double-spin asymmetry (A_{LL}) of pions and jets. On the other side, the transversely polarized proton collisions at RHIC enable the studies of the transverse spin structure, such as the transversity and Sivers distributions, as well as polarized fragmentation functions. These studies can be used to test universality of transverse-momentum dependent distributions (TMDs) with respect to e+p processes, and constrain their evolution effects. Furthermore, unpolarized measurements of differential cross sections of weak bosons at RHIC provide important constraints on the scale dependence of unpolarized TMDs in an x range ($0.1 < x < 0.3$) that naturally complements the phase space accessed at the LHC.
In this talk, we present the recent measurements for longitudinal and transverse polarization, besides selected unpolarized results. PHENIX newly redesigned detector, sPHENIX is being installed while STAR is currently installing a suite of new sub detectors in the forward region ($2.5 < \eta < 4$). How those upgrades will supplement previous Spin measurements at RHIC will also be briefly discussed.

Plenary Presentations / 109

Progress on Proton Charge Radius Measurements

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Progress on Proton Charge Radius Measurements

Ashot Gasparian
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Abstract

The proton charge radius is one of the fundamental quantities in physics. For the past seventy years it has been measured through elastic electron-proton scattering and ordinary hydrogen spectroscopy methods. Over the years, results from both methods generally agreed with each other within their experimental uncertainties. Unexpectedly, in 2010 (and 2013) two experiments from newly developed muonic hydrogen atomic spectroscopy method reported results up to six standard deviations smaller values than the accepted average from all previous experiments performed on ordinary hydrogen. This discrepancy triggered the well-known proton radius puzzle in hadronic physics. This talk will discuss the post-2010 progress in proton radius measurement methods together with new experimental results and plans for new experiments. In particular, a novel magnetic-spectrometer-free electron-proton scattering experiment (PRad), performed at Jefferson Lab in 2016, will be presented emphasizing its methods and results. Finally, the current status of the proton radius puzzle will be presented and discussed.

Transverse Momentum Structure (TMD) / 110

Azimuthal asymmetry in J/ψ electroproduction as a probe to linearly polarized gluon distribution at electon-ion collider

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We propose an estimate of cos(2ϕ) azimuthal asymmetry in J/ψ electroproduction, in an unpolarized electron-proton scattering process. We have used a non-relativistic QCD (NRQCD) framework for the J/ψ production rate. Within the kinematical range of the proposed Electron-Ion Collider (EIC), this can investigate the linearly polarised gluon distribution in the unpolarized proton. We compute the azimuthal asymmetry in the kinematic region: $z < 1$, where the leading contribution comes from the photon-gluon fusion subprocess: $\gamma^* g \to Q\bar{Q} + g$. We use two alternative models for TMDs to give the numerical estimate of the asymmetry: (1) the Gaussian-type parameterization and (2) the McLerran-Venugopalan model at small-x.

Polarized Sources and Targets / 111

Polarized H_2, D_2 and HD molecules and their possible use to feed a polarized H_2^+, D_2^+ or HD^+ ion source for stripping injection into storage rings

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With a dedicated apparatus it was shown that the nuclear polarization of hydrogen atoms and its isotopes, produced by a polarized atomic beam source (ABS), can be preserved during the recombination into molecules. In this way, polarized H_2 and D_2 molecules in hyperfine substates where both nucleons have equal spins are generated. In more recent experiments the ABS was used to determine the spin of hydrogen and deuterium atoms passing through in parallel. In this case, the nuclear spins of the protons and the deuterons can be determined separately to get HD molecules in any hyperfine substate, i.e. in any spin combination. One application of this technique can be the design of an intense H_2^+, D_2^+ or even an HD^+ polarized ion source for stripping injection at storage rings like COSY with polarization values above 0.8 and continuous intensities in the 10 μA range.

Polarized Sources and Targets / **112**

New aspects of storage-cell developments for the polarized internal target at LHCb

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Like the ANKE experiment at COSY a polarized internal storage-cell target in front of the LHCb detector is the aim of the LHCSpin Projekt at CERN. This target will be an openable T-shaped tube that will be fed with a beam of polarized hydrogen atoms from an atomic beam source (ABS) operating according to the Stern-Gerlach principle. One critical detail of such a storage cell is the surface coating that should minimize polarization losses due to wall collisions and recombination of the atoms into less polarized molecules. Due to the restrictions of the LHC operations a carbon coating seems to be the only option, but this has never been investigated for storage cells.

At the Institut für Kernphysik at Forschungszentrum Jülich, a setup is in use dedicated to study polarization losses in storage cells as a function of surface materials, temperature, magnetic holding fields or recombination processes. Therefore, this setup is a good tool to investigate carbon coated storage cells for further use at LHC.

Additionally, due to a slight modification of the ABS the influence of Lyman-α photons on the recombination process of hydrogen on the surface can be investigated.

In this talk, the setup of the storage cell investigations will be presented and the recombination process of hydrogen on a carbon surface will be discussed. The latter is also of interest for understanding the formation of molecular hydrogen in interstellar clouds.

Nucleon Helicity Structure / **113**

Measurement of Direct Photon Cross Section and Double Helicity Asymmetry at $\sqrt{s}$ = 510 GeV in $\vec{p}+\vec{p}$ Collisions at PHENIX

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The proton spin decomposition provides key information about the structure of the nucleons. Since late 1980s, experiments showed that the quark spin contributes only ∼30\% to the proton spin, with remaining part coming from gluon spin as well as quark and gluon orbital angular momentum. While the quark spin contribution was better constrained by polarized deep inelastic scattering (DIS), the gluon spin contribution remains less known, because it is probed through higher order processes (suppressed by ∼0.2 comparing to leading order processes) in DIS. The Relativistic Heavy Ion Collider (RHIC) is the only collider capable of producing two longitudinal polarized proton ($\vec{p}+\vec{p}$) beams. Direct photon, jet and charged pion productions in $\vec{p}+\vec{p}$ collisions can probe the gluon spin at leading order. Comparing with hadron productions, direct photon production is the most clean" channel, since there is little fragmentation involved, and is considered thegolden" channel. However, the relatively small direct photon cross section compared to the hadron productions made it a challenging observable, until the RHIC 2013 run, which provides the largest integrated luminosity (155 pb^{-1}) in $\vec{p}+\vec{p}$. In addition, the Electromagnetic Calorimeter at PHENIX has fine granularity to separate the two π^0 decay photons up to π^0 transverse momentum p_T of 12 GeV/c, and a shower profile analysis extends the γ/π^0 discrimination to beyond 20 GeV/c. These conditions finally made this "golden" measurement come to reality. In this talk, I will present the isolated and inclusive direct photon cross sections and their ratio for photon p_T of 6–30 GeV/c, as well as the isolated direct photon double helicity asymmetry (A_{LL}) for photon p_T of 6–20 GeV/c. When included in global analyses in the future, our results will provide an independent constraint on the gluon spin contribution to the proton spin.

Joint TMD - GPD - HELCITY - Future session EU timezone / 114

Nucleon isovector tensor charge from lattice QCD with physical light quark masses

Author: Ryutaro Tsuji[1]

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We will present the current status of nucleon structure studies with physical light quarks (m_π = 135 MeV) in two large spatial extents of about 10 and 5 fm. Our calculations are performed on 2+1 flavor gauge configurations generated by PACS collaboration with the stout-smeared $O(a)$ improved Wilson fermions and Iwasaki gauge action at β=1.82 corresponding to the lattice spacing of about 0.08 fm. In this talk, we mainly focus on nucleon isovector couplings of axial vector, scalar and tensor channels. Especially, the tensor coupling is known as the 1st Mellin moment of transversely parton distribution function and is itself related to the information of the quark-EDM.

Transverse Momentum Structure (TMD) / 115

First global extraction of the worm-gear TMD g_{1T}

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In this talk, we report on the first simultaneous extraction of the worm-gear function g_{1T}, one of the eight leading-twist TMDs. The study analyzes HERMES, COMPASS and JLab semi-inclusive deep-inelastic scattering data using Monte Carlo techniques. We provide a comparison of g_{1T} obtained from this experimental data with lattice QCD calculations, a large N_c analysis, and the Wandzura-Wilczek-type approximation.

Joint TMD - GPD - HELCITY - Future session US timezone / 116

Role played by the zero modes in the matching for the twist-3 PDFs

Authors: Shohini Bhattacharya[1]; Krzysztof Cichy[2]; Martha Constantinou[1]; Andreas Metz[1]; Aurora Scapellato[1]; Fernanda Steffens[3]

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The quasi-PDF approach has made it possible to extract the light-cone PDFs from lattice QCD. In this approach, one calculates matrix elements of space-like operators for boosted hadrons. Quasi-PDFs can be related to the light-cone PDFs through a perturbatively calculable matching coefficient. We address the matching for the very first time for the twist-3 PDFs $g_T(x)$ and $h_L(x)$. In this talk, we focus on potential complications in the matching due to the presence of singular zero-mode contributions.

Joint TMD - GPD - HELCITY - Future session US timezone / 117

Lattice results on twist-3 parton distributions

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Twist-3 distributions are very important quantities for the study of hadron structure, and presently they are poorly known experimentally. In this talk, we present the first-ever results on the proton

iso-vector twist-3 PDFs $g_T(x)$ and $h_L(x)$, obtained from lattice QCD. We employ the quasi-PDF approach, which is based on computation of correlation functions between two boosted proton states at finite momentum, that are eventually matched to the light-cone distributions through perturbative matching formulae, that we developed specifically for twist-3 PDFs.
Our calculations are performed on a gauge ensemble with two degenerate light quarks, a strange and a charm quark ($N_f = 2 + 1 + 1$), with lattice spacing $a = 0.093$ fm and pion mass $M_\pi = 270$ MeV.
The proton is boosted to 0.83 GeV, 1.25 GeV and 1.67 GeV to check momentum convergence. On the same ensemble we also extract the twist-2 counterparts and test the Wandzura-Wilczek approximation.
Extending the methodologies developed for PDFs, we also present preliminary results for twist-3 GPDs.

Future facilities and experiments / **118**

Single-spin asymmetry measurements in inclusive production of K^0s and ω (782) mesons at U70 (Protvino).

Authors: Konstantin Novikov[1]; N.K. Kalugin[2]; V.V. Mochalov[2]; V.V. Moiseev [2]; M.B. Nurusheva[3]; V.L. Rykov [3]; P.A. Semenov[2]; A.N. Vasiliev[2]

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The SPASCHARM project is aimed at studying a fundamental problem of modern particle physics, such as the mechanism of spin asymmetries in the production of hadrons. The goal of the first stage of the SPASCHARM experiment at the U-70 accelerator in Protvino is the study of single-spin asymmetry in different reactions using negative pion beam with a polarized proton target. SPASCHARM setup was commissioned and will start data taking this fall. Second stage of the SPASCHARM experiment will measure spin effects using polarized proton and antiproton beams.

The specific task of this talk is to study possibility to measure single-spin asymmetry in inclusive production of K^0s and ω (782) mesons at negative pion and polarized antiproton beams. The measurement of inclusive production of K^0s and ω (782) mesons with polarized antiproton beam are planning for the first time. Expected statistic accuracies of single-spin asymmetry in inclusive production of K^0s and ω (782) mesons are presented. The expected accuracy is 1-2% in different kinematic regions.

Spin in Nuclear Reactions and Nuclei / **119**

POLARIZATION TEST FOR QUASI-FREE KNOCKOUT OF NUCLEON FROM NUCLEAR SHORT-RANGE CORRELATED NN PAIR

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Short-range correlated (SRC) NN pairs play an important role in structure of atomic nuclei and are actively studied using electron and proton beams [1]. Recently the reaction ^{12}C+p$\to^{10}$A+pp+N was studied at BM@N in JINR [2] using the ^{12}C beam at energy of 4 GeV/nucleon interacting with the hydrogen target to probe the SRC pairs {pN} in the ^{12}C. The pp scattering in the subprocess

p+{pN}⊠p+p+N occured at the scattering angles ~ 90° in the pp c.m.s. and all three final nucleons were detected as well as the residual nucleus ^{10}A. For theoretical analysis of this reaction [3] is used a properly modified approach developed earlier [4] to describe the quasi-elastic knock-out of fast deuterons from the light nuclei ^{12}C and ^{7,6}Li by protons in the reactions (p,pd) and (p,nd). A basic assumption in theoretical description of SRC NN correlations in nuclei is a factorization of the two-nucleon momentum distribution in nucleus $n(k_1, k_2)$ over the internal, $n_{rel}(q_{rel})$, and the c.m.s., $n_{cm}(k_{c.m.})$, momenta [1]. For the internal $n_{rel}(q_{rel})$ distribution the deuteron (or singlet deuteron) wave function squared is used for the realistic NN-interaction potentials. Relativistic effects in the quasi-elastic knockout of nucleon from the SRC pair p+{NN}⊠p+N+N are taken into account in the light-front dynamics [5] similarly to the deuteron breakup reaction p+d⊠p+p+n. According to the results of the data analysis of the ^{12}C+p⊠^{10}A+ pp+N reaction [2] the initial and final state interaction (ISI&FSI) with nuclear medium is nonimportant in the reaction in question at kinematic conditions of the BM@N experiment. Here we estimated the ISI&FSI effects within the eikonal approximation using the Glauber model for the N-^{10}A scattering. The one-loop approximation with elastic N-^{10}A rescatterings was applied and the ISI&FSI effect was found to be moderate. However, another question concerning the mechanism of the subprocess p+{NN}⊠p+N+N and the role of ISI&FSI in it is much less clear. Only in case of dominance of the quasi-free mechanism (or impulse approximation) of the nucleon knockout in the subprocess p+{NN}⊠p+N+N one can extract the internal momentum distribution $n_{rel}(q_{rel})$ from the data on the reaction ^{12}C+p⊠^{10}A+ pp+N. One can show (see Ref. [6] and references therein), that the tensor analyzing power T_{20} of the reaction p+d⊠p+p+n for the quasi-free mechanism of the nucleon is easily expressed via the ratio u(q)/w(q) of the S- and D- components of the deuteron wave function in the momentum space u(q) and w(q), respectively, and has a very specific behavior as a function of the module of q [6]. Therefore, a measurement of the T_{20} in the reaction p+d⊠p+p+n at the same kinematics as for the subprocess p+{NN}⊠p+N+N in the reaction A(p,ppN)B, i. e. at large momentum of the nucleon spectator and large pp-scattering angle ~ 90°, and a subsequent comparison with the results of the IA calculation of the T_{20}, will provide a crucial test for the quasi-free mechanism of this subprocess. A similar test based on the measurement of the T20 of the reaction e+d⊠ e+p+n can be used to check quasi-free mechanism of the nucleon knockout by electron from the SRC NN pair in the reaction A(e,epN)B.

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1. O. Hen et al., Rev. Mod. Phys. 89 (2017) 045002.
2. M. Patsyuk et al. Nature Phys. 17 (2021) 693; arXiv:2102.02626 [nucl-ex].
3. Yu.N. Uzikov, Izv. RAN, Ser. Fiz. 84 (2020) 580.
4. M.A. Zhusupov, Yu.N. Uzikov, Fiz. El. Chast. At. Yadr. 18 (1987) 323.
5. Yu.N. Uzikov, EPJ Web Conf, 222 (2019) 03027.
6. S.L. Belostotski et al., Phys. Rev. C 56 (1997) 50.

Polarized Sources and Targets / 120

NMR With Machine Learning

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Constant current continuous wave Nuclear Magnetic Resonance (NMR) has been an essential tool for polarized target experiments in Nuclear and High-energy physics. Q-meter based phase-sensitive detection can provide accurate monitoring of the polarization over the course of a scattering experiment with limitations due to some operational parameters. In this talk, we present recent studies of improved signal to noise in polarization measurements as well as reliable measurements outside of the designated range of the Q-meter's operational parameters with the use of machine learning (ML).

Fundamental Symmetries and and Spin Physics Beyond the Standard Model / 122

Weinberg operator contribution to the hadronic CP violation

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The Weinberg operator (chromo-electric dipole moment of gluon) is a CP violating quantity generated in many candidates of new physics beyond the standard model, and it contributes to observables such as the electric dipole moments (EDM) of the neutron, nuclei and atoms.
In this presentation, we review the present understanding of the Weinberg operator.

Future facilities and experiments / 123

AI in Spin Physics and the future of spin at Fermilab

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The use of the Fermilab main injector proton beam with an energy of 120 GeV and a 4.4-second spill every minute in combination with a polarized target provides a unique opportunity for future spin physics experiments. New technology in RF manipulated dynamically polarized (DNP) target systems rely on artificial intelligence to optimally configuration the target polarization state using the signal from continuous wave nuclear magnetic renounce (NMR). The target spins can be autonomously oriented in the time between spills allowing for the access of novel observables. Machine learning tools are advancing instrumentation potential as well as information extraction in Spin Physics. Some examples are provided, with a focus on possible future experiments at Fermilab.

Polarized Sources and Targets / 125

SpinQuest Polarized Target: An Overview

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The SpinQuest experiment at Fermilab aims to extract Sivers functions for the sea quarks in the range of $0.1 < x_B < 0.5$ through single spin asymmetry measurements of di-muon pairs resulting from the Drell-Yan process. The proposed beam intensity is 1.5×10^{12} of 120 GeV unpolarized proton/sec. The experiment utilizes a transversely polarized fixed target system which consist of a 5T superconducting magnet, NH3 and ND3 targets, a 4He evaporation refrigerator, a 140 GHz microwave source and a large pumping system. The expected average target polarization is 80% for protons, and 32% for deuterons. The polarization will be measured using Q-meter based NMR system. An overview of the polarized target system, including polarization measurements will be presented in this talk.

Transverse Momentum Structure (TMD) / 126

SU(3)-flavor TMD PDFs extraction with global fits & ANN

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Transverse Momentum Dependent Parton Distribution Functions (TMD PDFs) can be extracted from the processes that are corresponding to multiple kinematic scales such as Drell-Yan (DY), Semi Inclusive Deep Inelastic Scattering (SIDIS) and e+ e– annihilation. Among the eight leading- twist TMD PDFs, there are two time-reversal odd TMDs, namely Sivers function & Boer-Mulders function, which represent the correlation between the spin of the quark and the spin of the hadron. These T-odd TMD PDFs have conections to the partons' orbital angular momenta contributing to the overall angular momentum of the hadron. Not only implementing global fits to the available data, but also an Artificial Neural Network (ANN) can be trained with regression to simulate these time-reversal odd TMDs. A preliminary analysis in the case of $SU(3)_{flavor}$ TMDs extraction using an ANN with available experimental data will be presented in this talk.

Fundamental Symmetries and and Spin Physics Beyond the Standard Model / 127

Muon g-2/EDM Experiment at J-PARC

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In the anomalous magnetic moment of muons (muon g–2), there was a discrepancy of more than 3σ between the Standard Model prediction and the experimental value measured with an accuracy of 0.54 ppm by Brookhaven National Laboratory (BNL) E821 experiment, and it has long been argued that this might be a sign of new physics beyond the Standard Model. Recently, Fermilab's experimental group improved BNL's experimental equipment and conducted experiments in a similar method. The result is consistent with the previous experiment, and the discrepancy between the average of the two experiments and the Standard Model prediction was updated to 4.2σ. As a result, expectations for new physics discoveries are rising even more. However, since the two experiments employ the same method, it is extremely important to measure with different new methods and confirm the discrepancy. To validate the discrepancy, an experiment with a completely independent approach from the previous two experiments is planned at Japan Proton Accelerator Complex (J-PARC). The J-PARC experiment aims to measure the muon g–2 with a precision of 0.1 ppm and search for muon electric dipole moment with a sensitivity of 1.5×10^{-21} e·cm. The overall design of the experiment and its preparation status will be presented.

Plenary Presentations / 128

T-violation in neutron scattering

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The fundamental symmetry violation can be studied by using nuclear reactions with polarized neutrons beam and target nuclei. The large enhancement of the parity violation was observed in the neutron capture reactions for some nuclei. It is predicted that time reversal symmetry violation is also enhanced with the same mechanism. Our recent results of 139La(n, γ) reaction suggested that the enhancement is large enough to search T-violation with high sensitivity, which can be reach to the sensitivity of neutron electric dipole moment and which has different systematics. We are performing the research and development for the T-violation search experiment at J-PARC, for example, details of nuclear reactions with candidate nuclei and that of experimental setup. We are also developing the polarization technique for both of neutron beam and target nuclei, so-called spin exchange optical pumping and dynamic nuclear polarization, respectively.

Spin in Nuclear Reactions and Nuclei / **129**

Development of a polarized proton target for spin-correlation coefficient measurements

Author: Atomu Watanabe[1]

Co-authors: Kenichiro Tateishi [2]; Kimiko Sekiguchi [1]; Tomohiro Uesaka [3]; Yuko Saito [1]

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The study of three-nucleon forces (3NFs) is essential for clarifying various nuclear phenomena. The 3NFs arise naturally in the meson exchange model as well as in the framework of chiral effective field theory (EFT). With the aim of pinning down the 3NF effects in comparison with the rigorous numerical calculation based on the chiral EFT, we plan to measure the complete set of spin-correlation coefficients for deuteron-proton elastic scattering at intermediate energies (~ 100 MeV/nucleon). For the measurement of spin-correlation coefficients, we develop the polarized proton target.

We require the following conditions for the polarized proton target system: 1) covering a wide angular range in the horizontal and vertical scattering plane, 2) high polarization ($> 20\%$), and 3) a low magnetic field (~ 0.1 T). We adopt a dynamic nuclear polarization (DNP) with photo-excited triplet electron spins (so-called triplet DNP method) to produce polarized protons. The polarized target is a single crystal of naphthalene doped with pentacene and has a size of $\phi 10 \times 3$ mm^3. In this conference, we report the newly developed polarized proton target system.

Plenary Presentations / **130**

Measurement of muon g-2

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At present, there is a discrepancy between the Standard Model calculation and the measured value of the anomalous magnetic moment of the muon a_μ. This disagreement may arise from new physics, or from an omission in either theory or experiment. Ongoing international efforts on both fronts aim to resolve the source of this discrepancy. This talk will present the progress and prospects of precision measurements of a_μ.

Acceleration, Storage and Polarimetry of polarized Beams / **131**

HIGH VOLTAGE DESIGN AND EVALUATION OF WIEN FILTERS FOR THE CEBAF 200 keV INJECTOR UPGRADE

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Our contribution describes design, fabrication and testing of the high voltage system to upgrade the Wien spin rotator to be compatible with the 200 keV electron beam. This required Solidworks modeling, CST and Opera electro- and magnetostatic simulations, upgrading HV vacuum feedthroughs, and assembly techniques for improving electrode alignment. The electric and magnetic fields required by the Wien condition and the successful HV characterization under vacuum conditions are also presented.

Acceleration, Storage and Polarimetry of polarized Beams / **132**

New Spin Tracking Software Developed For General Particle Tracer

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A new particle spin tracking feature has been developed and implemented within General Particle Tracer (GPT). Simulating polarized particles under various conditions within accelerators requires the classical dynamics and time-dependent spin equation of motion. These equations capture the particles behavior as it interacts with electro-magnetic fields. The GPT-Spin extension is able to track particle spin coordinates in GPT using the generalized Thomas-BMT equation. GPT is based on fully relativistic 3D particle-tracking techniques, providing a solid basis for the study of all 3D and non-linear effects of charged-particles dynamics, now including spin, in electro-magnetic fields. New or modified GPT elements have been implemented to initialize and simulate an arbitrary particle beam with spin. Built in or custom elements and field maps can all be used to perform highly specialized calculations for specific applications. This work will present benchmark simulations and details of the newly available GPT -Spin feature.

Transverse Momentum Structure (TMD) / **133**

Transverse Single Spin Asymmetry of Forward Neutrons at PHENIX

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Very forward neutron production cross sections in proton proton collisions are well described by a one pion exchange (OPE) mechanism. However, the simple OPE model alone was not able to explain the large transverse single spin asymmetry (A_N) that was discovered at RHIC in polarized proton

proton collisions. An interference between the spin-flip pion exchange and non-flip a_1-Reggeon exchange could create asymmetries, and such a model reasonably describes the measurements.
More interestingly, recent PHENIX measurements in p+A collisions at 200 GeV show surprisingly strong nuclear dependence of A_N, resulting from the interplay of different neutron production mechanisms. To understand the mechanisms in detail explicit transverse momentum p_T and longitudinal momentum fraction x_F dependent analyses are performed. In addition, correlation analysis with other detector activity provides additional information on how different interactions contribute to the asymmetry.
For a large phase space coverage in x_F and p_T it is also essential to make the measurements over a wide range of center of mass energy of collisions. PHENIX has taken polarized proton proton collision data at $\sqrt{s}$ = 62, 200, 500 and 510 GeV.
At PHENIX the Zero degree calorimeter (ZDC) is used for neutron detection in conjunction with the Beam Beam Counter (BBC) for tagging various event topologies. We will show results for explicit p_T and x_F dependence of A_N at $\sqrt{s}$ = 200 GeV in $p\uparrow + p$, $p\uparrow + Al$ and $p\uparrow + Au$ collisions. We will also show the current status of the center of mass energy dependence analysis for $p\uparrow + p$ collisions.

Transverse Momentum Structure (TMD) / 134

Sivers azimuthal asymmetry in inelastic J/ψ leptoproduction

Authors: Francesco Murgia[1]; Umberto D'Alesio[2]; Asmita Mukherjee[3]; Sangem Rajesh[None]; Cristian Pisano[None]

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We study the Sivers azimuthal asymmetry for J/ψ production in semi-inclusive deeply inelastic scattering, with the aim of gaining information on the poorly known gluon Sivers function. We concentrate on the J/ψ low transverse momentum region, adopting the transverse-momentum dependent generalized parton model (GPM), and its color gauge invariant extension (CGI-GPM), which includes final state interactions at leading order. We consider the nonrelativistic QCD (NRQCD) scheme for the quarkonium formation mechanism. We compare our results for unpolarized cross sections and the Sivers asymmetry with available data, respectively from HERA and COMPASS, giving estimates for the asymmetry in the kinematical regime of the future Electron-Ion Collider (EIC).

Joint BSM - Accelerator - Future Session EU timezone / 135

Polarization facilities at the JINR accelerator complex

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Polarization facilities are being developed at the JINR accelerator complex in the framework of the polarization research program under the NICA project. Those are the polarized deuteron and proton source SPI, SPI low energy and linac output polarimeters, and the absolute polarimeter at the NICA collider. The status of the above facilities and the results achieved are presented.

Future facilities and experiments / **136**

Machine Learning Online Monitoring for the SpinQuest experiment at Fermilab

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The SpinQuest experiment (E1039) is a transversely polarized fixed target experiment at Fermi National Accelerator Laboratory designed to measure the sea-quark Sivers functions via the Drell-Yan process. An unpolarized beam of 120-GeV protons will interact with a transversely polarized proton or deuteron target which will produce Drell-Yan dimuon events. Those muons will be detected in the spectrometer which allows for the extraction of the single-spin transverse asymmetry. Fast online monitoring is necessary to scan the quality of the incoming data and the general health of the experiment. Machine learning techniques can be used to speed the reconstruction of dimuon events and monitor any false asymmetry measured in each spill. Additionally, slow controls information can be integrated, allowing for automation of diagnostics and quality checks during the experiment, potentially reducing the overall systematic error of the experiment.

Polarized Sources and Targets / **137**

Dynamical Behavior of the SpinQuest Target Polarization due to Beam Heating and Radiation Damage

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The SpinQuest experiment at Fermilab will utilizes a high intensity 120 GeV proton beam incident on a transversely polarized target. The likely behavior of the SpinQuest polarized target due to beam heating and radiation damage has been recently analyzed. The target temperature will increase due to the beam heating which can cause local depolarization of the target material. The temperature of the target also depends on heat removal by the helium evaporation refrigerator. A simulation based on the finite-difference method was applied to obtain the final temperature of the target under the SpinQuest configuration. The radiation level in the target material was studied using GEANT to obtain the intensity of secondary particle production along the target length. Finally, using the target temperature and beam irradiation information, a LabView-based simulation was developed to calculate the depolarization in the target material as a function of position along the target length. In this talk, I will present the degree of dynamic target depolarization and the information and approach intended for reducing the systematics for these effects.

Fundamental Symmetries and and Spin Physics Beyond the Standard Model / **138**

Search for permanent EDM using Fr atoms

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The existence of the permanent Electric Dipole Moment (EDM) implies the time reversal symmetry violation. This violation directly means CP violation by the CPT theorem, and it would be expected to explain the observed matter-antimatter asymmetry. The electron EDM, which is the possible signal of the T-violation predicted by the Standard Model (SM) is too small to be measured with current experimental technique and the larger EDM would indicate a new physics beyond SM. This tiny EDM for the electron can be enhanced by the relativistic effects in the heavy atoms such as francium (Fr).
In this report, we will see the overview of the experiment of the search for EDM using two isotopes of Fr developed at RIKEN. One is 210-Fr, produced by a nuclear fusion-evaporation reaction between gold target and oxygen beam supplied from AVF cyclotron, and the other is 221-Fr, produced from the alpha decay of 225-Ac, which can be used as the generator for 221-Fr, and has a long lifetime ~ 10 days. Both isotopes have large enhancement factor of 895 compared with electron EDM, which can be calculated very precisely with the relativistic coupled cluster theory. The 221-Fr nucleus has, on the other hand, a large octupole deformation effect and can become the candidate to search for the nuclear EDM.
We conducted the high intensity surface ionizer to produce the Fr ions, the neutralizer which is used to recombine the electron to the Fr ion, and the Magneto-optical trap (MOT) for the Fr cooling and trapping. All the experimental apparatus were successfully developed and operated, and also the development of the new experimental apparatus to produce the high intensity 225-Ac source, and laser cooling for 221-Fr is now in pogress. The present status and expected sensitivity for the EDM with the trapped cold Fr atoms will be discussed.

Transverse Momentum Structure (TMD) / 139

Probing gluon TMDs via open heavy flavor quark production at the EIC

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In this talk, I will introduce our recent study on the probing transverse momentum-dependent gluon Sivers function in open heavy flavor quark production at the future EIC. We derive the theoretical framework to calculate heavy-quark pair production in the small transverse momentum region. Based on the factorization and resummation formula, we resum large logarithms in the small qT region and present the theoretical predictions for the single-spin asymmetry.

Future facilities and experiments / **140**

Online Reconstruction on GPUs for J/ψ TSSA Study at SpinQuest

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E1039/SpinQuest is a fixed target experiment at Fermi National Accelerator Laboratory that uses a transversely-polarized target to explore the sea quark and gluon Sivers functions via the measurement of the transverse single spin asymmetry (TSSA) for a number of physics processes including J/ψ, ψ' and Drell-Yan production. The experiment employs a 120-GeV extracted proton beam colliding with transversely-polarized NH3 and ND3 cryogenic targets. The SpinQuest spectrometer is optimized to detect the oppositely-charged muon pair produced in these processes. In pursuit of these asymmetry measurements, we are developing an advanced graphical processing unit (GPU) based multi-threaded framework that allows for an efficient parallelization of the online data processing flow and track reconstruction along with diagnostics and visualization tools. In this talk, I will report the progress of the ptimization of the offline track reconstruction in GPU by this autumn to reach real-time data visualization and monitoring. I will also present results estimating the anticipated precision of TSSA measurement via J/ψ production from the first SpinQuest production data.

Joint GPD - Helicity session / **141**

Novel CFFs Extraction in Unpolarized DVCS

Authors: Liliet Calero Diaz[1]; Dustin Keller[2]; Zulkaida Akbar[2]

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Over the last 20 years there has been intense experimental activity dedicated to the measurement of observables to help build a 3D description of the nucleon. Generalized parton distributions (GPDs) describe complementary aspects of the structure of hadrons, providing qualitative and quantitative information about the partonic structure and dynamics such as orbital angular momentum. The formulation of the DVCS cross section is parametrized in terms of Compton Form Factors (CFFs) which are convolutions of GPDs with coefficient functions computed from perturbative QCD.This talk presents the most recent DVCS helicity amplitude formulations aimed at extracting CFFs and explores their distinctive kinematic characteristics.

Nucleon Helicity Structure / **142**

Recent Longitudinal Spin Results with Charged Pions and Jets at PHENIX

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Operated at the Relativistic Heavy Ion Collider at Brookhaven until beginning its recent upgrade into sPHENIX, the PHENIX experiment has collected a wealth of data from polarized proton collisions. Analysis of these data sets continues to offer insight into the spin structure of the proton. In particular, RHIC's polarized proton-proton data help constrain polarized PDFs in the proton, and the double spin asymmetry of various processes is sensitive to gluons at leading order. I will give a brief overview of the detector and recent results in charged pion and jet asymmetries, as well as a discussion of the impact these measurements have on our understanding of parton polarizations.

Transverse Momentum Structure (TMD) / 143

Transverse Single Spin Asymmetries of Midrapidity Heavy Flavor Electrons and Charged Pions in 200 GeV $p^{\uparrow} + p$ Collisions at PHENIX

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Understanding the transverse spin and momentum structure of the proton is of large interest to the nuclear physics community and it is one of the main goals of the spin physics program at the Relativistic Heavy Ion Collider (RHIC). Transverse single spin asymmetry measurements for particles produced in proton-proton collisions provide insight into initial and final state spin-momentum and spin-spin parton-hadron correlations. In particular, electrons from heavy flavor decays provide access to initial state spin-momentum correlations of gluons in the proton, while charged pions provide access to both initial and final state transverse spin effects of quarks and gluons. Electrons and charged pions are measured at midrapidity at PHENIX using the central arm spectrometers which consist of an electromagnetic calorimeter, a ring-imaging Cherenkov detector, as well as drift and pad chambers. In addition, the heavy flavor decay electron analysis uses the silicon vertex detector in order to veto background from conversion electrons. Recent results from both the electron and charged pion measurements from the 2015 running period (200 GeV $p^{\uparrow}+p$) will be presented.

Plenary Presentations / 144

Nuclear spin-isospin responses studied by nuclear reactions: A tribute to Munetake Ichimura

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Progress in the nuclear spin physics studied by nuclear reactions is briefly reviewed with particular emphasis on the contributions of Munetake Ichimura and his research-group.
Much of his recent work was based on a comprehensive framework consisting of a distorted wave impulse approximation (DWIA) with response function calculated by a continuum random phase approximation(RPA).
We pay special attention to two contrasting problem.
One is the quenching of the total Gamow-Teller (GT) transition strength with respect to the model-independent GT sum rule (Ikeda's sum rule).
The other is the enhancement of the pionic modes at relative large momentum transfers as a precursor phenomenon of pion condensation.
A main aim of this review is to gain an overall understanding of the behavior of these spin-isospin modes.

Furthermore, recent developments in the isospin dependence of the spin-isospin residual interaction studied by the GT resonances for unstable nuclei as well as the tensor correlation effects observed in the spin-dipole resonances are also addressed.

Transverse Momentum Structure (TMD) / 145

Geometric model for Drell-Yan processes and TMDs

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The tensor polarization of virtual photons revealed in angular distributions of Drell-Yan processes may be described in simple geometric model.
The results are compared with collier and fixed target data. The model compatibility with pQCD is discussed.
The contribution as a background for TMDs (in particular, Boer-Muders distribution) studies is considered

Form Factors and GPDs / 146

Time-like gravitational formfactors and shear viscosity

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The extraction of time-like gravitational formfactors from exclusive meson pair production is discussed. The special attention is payed to structures which should cancel between quarks and gluons but may be non-zero for quarks. In particular, dipole term may be associated with shear viscosity. Its studies in exotic hybrid mesons production is addressed. The smallness of the respective GDA may be an analog of smallness of shear viscosity in holographic approach,

Spin in Nuclear Reactions and Nuclei / 147

Proton-3He elastic scattering at intermediate energies

Authors: Kimiko Sekiguchi[1]; Atomu Watanabe[1]; Shin'nosuke Nakai[1]; Yasunori Wada[1]; Kenjiro Miki[1]; Takashi Ino[2]; Kichiji Hatanaka[3]; Hiroki Kanda[4]; Nobuyuki Kobayashi[4]; Yukie Maeda[5]; Hooi Jin Ong[4]; Hideyuki Sakai[6]; Atsushi Tamii[7]; D. T. Tran[4]; Tomotsugu Wakasa[8]; Takashi Wakui[None]; Masatoshi Itoh[9]

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Few nucleon systems offer good opportunities to investigate nuclear interactions. The recent topic of few-nucleon systems is to explore the properties of three-nucleon forces. We performed proton-3He elastic scattering at incident proton energies of 65 and 100 MeV with a polarized proton beam in conjunction with the polarized 3He target system. In the conference, we present the data in comparison to the rigorous numerical calculations of four-nucleon scattering based on the various nuclear potentials.

Spin in Nuclear Reactions and Nuclei / **148**

Axial Vortical Effect and polarization of resonances in heavy-ion collisions

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The axial vortical effect is considered for currents corresponding to hadrons of spin 1/2, 1 and 3/2. The density matrix approach suggested by Zubarev and developed by Becattini and collaborators is applied. The duality between statistical description in usual Minkowski space and geometry in the space with conical singularity is addressed. The interplay with anomalies calculations is outlined. The possible phenomenological consequences for polarization of hadrons in heavy-ion collisions are discussed.

Nucleon Helicity Structure / **149**

The role of the chiral anomaly in polarized deeply inelastic scattering: Topological screening and emergent axion-like dynamics

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I'll discuss the role of the chiral anomaly in deep inelastic scattering (DIS) of electrons off polarized protons employing a worldline formalism, which is a powerful framework for the computation of perturbative multi-leg Feynman amplitudes. I'll demonstrate how the triangle anomaly appears at high energies in the DIS box diagram for the polarized structure function $g_1(x_B, Q^2)$ in both the Bjorken limit of large Q^2 and in the Regge limit of small x_B. I'll show that the infrared pole of the anomaly appears in both limits. I will introduce an effective action for spin dependent observables at small x that follows from the cancellation of the infrared pole in the matrix element of the anomaly.

This effective action, consistent with anomalous chiral Ward identities, is controlled by two dimensionful scales in Regge asymptotics. The first is the color charge squared per unit area, while the second is the pure Yang-Mills topological susceptibility.

Acceleration, Storage and Polarimetry of polarized Beams / 150

Measurement of Polarization Transfer in Møller Scattering

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Even though Møller scattering has been a subject of several precise experiments, studies of the final spin state in Møller scattering of polarized electron beams offer a unique tool for testing the fundamnetal predictions of relativistic quantum mechanics. The aim of this work was to measure the polarization transfer in Møller scattering (the ratio of the transverse polarization vector component length of the electron in the final state to the incoming-beam polarization); it is, to our knowledge, the first such measurement.

A dedicated Mott polarimeter was designed and constructed. In addition to the standard polarimeter layout, it was equipped with a tagging detector, which was used for a coincidence trigger allowing to record Møller scattering events. The reduction of background was achieved by an offline subtraction of data collected without the target in the polarimeter, as well as by event selections regarding electron energy and timing of the signals from both recorded electrons.

The beam polarization, as well as the mean polarization of the electrons in the final state of symmetric Møller scattering, were measured. The final results were calculated assuming an analyzing power value obtained from a dedicated Monte Carlo simulation. The polarization transfer was measured for two incident-beam polarization orientations with respect to the Møller scattering plane. The results were found to be in agreement with the predictions of relativistic quantum mechanics.

Spin in Nuclear Reactions and Nuclei / 151

Explore double slit interference effect with linearly polarized photons in UPCs

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In this talk, I will disscuss the cos 2φ azimuthal angular correlation in rho^0 meson production in ultraperipheral heavy ion collisions. The asymmetry essentially results from the linear polarization of incident coherent photons, which just has been experimentally confirmed by the recent STAR measurement. The asymmetries evaluated in the dipole model for rho^0 photoproduction at RHIC and LHC energies are shown to be rather sizable, and is in reasonably good agreement with the STAR measurement. I will show that the double slit interference effect plays a key role in yielding the distinctive diffractive pattern of the observed asymmetry.

Low energy spin physics with lepton, photon and hadron probes / 152

Spin effects in low-energy electron-nucleon scattering with two-photon exchange: Analysis based on 1/N_c expansion of QCD

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The transverse single-spin asymmetry in inclusive electron-nucleon scattering, e + N(S_T) -> e' + X, represents a pure two-photon exchange observable and is of fundamental interest for exploring higher-order QED effects in electron scattering. We compute this observable in the resonance region, where excitation of Delta isobars occurs in both intermediate and final states. We employ a novel theoretical method based on the large-N_c limit of QCD, which allows us to consistently combine nucleon and Delta states and predict the elastic, inelastic, and inclusive spin-dependent cross section. Our results aim at disentangling the different contributions of nucleon and Delta states organizing them according to their 1/N_c scaling. The case of the target single spin asymmetry will be discussed in detail. Our predictions could be tested in future measurements of electron-nucleon scattering with polarized targets in the few-GeV energy range. Such experiments would complement earlier measurements of the inclusive single-spin asymmetry in the DIS regime (JLab, HERMES) and allow one to study the unknown dependence of two-photon exchange dynamics on the energy/momentum of the probe.

Polarized Sources and Targets / 153

A High-Magnetic-Field Polarized 3He Target for JLab's CLAS12

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Polarized ^{3}He nuclear targets have been invaluable surrogates for polarized neutron targets in spin-dependent scattering studies of the quark and gluon structure of matter. Traditional polarized ^{3}He targets have seen dramatic improvements in the last three decades, however they have been limited in their use in spectrometers that utilize high-magnetic-field tracking systems, such as Jefferson Lab's CLAS12 spectrometer. Developments in high-magnetic-field metastability exchange optical pumping of ^{3}He, recently brought to bear for a polarized ^{3}He ion source for RHIC and the EIC, offer a path to a high-field polarized ^{3}He fixed target. By combining these techniques with a double-cell cryogenic target design, such as the one used for the MIT-Bates 88-02 experiment, polarization and target density comparable to traditional polarized ^{3}He targets can be reached while within a high magnetic field environment. We will discuss the conceptual design for such a target, preview a concept for achieving polarization transverse to the incident beam with this method, and show our progress in this target's development.

Joint BSM - Accelerator - Future Session EU timezone / 154

A new search for time-reversal symmetry-breaking in muon decays

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One of the key open questions on the nature of the neutrino is whether it is a Dirac or a Majorana particle. If the neutrino is a Majorana particle, then the interference terms that break the time-reversal symmetry of muon decay appear as the transverse spin polarization of the decay electron [1]. Experiments have been performed at Paul Scherrer Institute to measure the spin polarization of positrons in positive muon decays, using Bhabha scattering and annihilation-in-flight [2]. No significant transverse polarization of decay positrons has been observed so far, and experiments with higher sensitivity can push the scope of searches for physics beyond the Standard Model. This topic is revisited by investigating the possibility of a new experiment using a high-intensity pulsed muon beam at J-PARC. As a result of the Monte-Carlo simulations, the prospect of improving the measurement precision by at least one order of magnitude was obtained. In this contribution, the outline of the new experiment and the design of the polarimeter will be discussed.

[1] M. Doi, T. Kotani, H. Nishiura, K. Okuda, and E. Takasugi, Prog. Theor. Phys. 67, 281 (1982).
[2] N. Danneberg et al., Phys. Rev. Lett. 94, 021802 (2005).

Transverse Momentum Structure (TMD) / 155

Extracting the Λ polarizing Fragmentation Function from Belle e^+e^- data within the TMD formalism.

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Data from the Belle Collaboration for associated production (with a light unpolarized hadron) and single-inclusive production of transversely polarized Λ-hyperons in e^+e^- annihilation processes allowed to extract, for the first time, the Λ polarizing fragmentation function, by adopting a simplified TMD approach.
Recent theoretical developments on the computation of cross sections for single-inclusive hadron production in e^+e^- annihilation, within a Soft Collinear Effective Theory approach, combined with the CSS formalism for the double-hadron production case, can be used to perform a renewed analysis, adopting a proper TMD factorization scheme. Preliminary results and a comparison between the two analyses are presented.

Transverse Momentum Structure (TMD) / 156

Beam spin asymmetries of $\pi^+\pi^0$ and $\pi^-\pi^0$ dihadrons from SIDIS at CLAS12

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Spin asymmetries provide a wide range of insights into nucleon structure and hadronization. Recent measurements of beam spin asymmetries of $\pi^+\pi^-$ dihadrons from SIDIS at CLAS12 provide the first empirical evidence of a nonzero $G_1^\perp$, the parton helicity-dependent dihadron fragmentation function (DiFF) encoding spin-momentum correlations in hadronization. These measurements have been extended to help further characterize $H_1^\perp$ and $H_1^<$, the DiFFs dependent on parton transverse spin, via a multidimensional partial wave analysis, giving access to the dependence on the interference of dihadrons of particular polarizations. Reconstruction of π^0s allows for further extension of these measurements to $\pi^+\pi^0$ and $\pi^-\pi^0$ dihadrons. The DiFFs describing $\pi^+\pi^-$ production differ from those describing $\pi^+\pi^0$ and $\pi^-\pi^0$ production, which involve different quark flavors along with a strong suppression of the exclusive diffractive contribution. This presentation will focus on comparisons of beam spin asymmetries for these three dihadron flavors, which will help shed light on a more comprehensive picture of dihadron fragmentation.

Polarized Sources and Targets / 158

A versatile bulk superconducting MgB_2 cylinder for the production of holding magnetic field for polarized fuels and targets

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The production of an internal magnetic field in a compact space is a challenging problem and a versatile solution is being pursued. The property of a hollow superconductor is exploited in order to trap a specific configuration of magnetic field, which could shield the interior from externally applied fields. This can be achived applying the desired magnetic configuration during the cooling process through the transition temperature.
This solution, in the longitudinal field configuration, would be useful for polarized fuel for nuclear fusion test. In the transverse field configuration, instead, would be useful for transversely polarized nuclear target.
A bulk superconducting MgB_2 cylinder has been characterized measuring the interior field retention, the capability to exclude an externally applied field and the corresponding long-term stability performance. The measurements have been done just in its center at 1 T transverse magnetic field at around 13 K.
The present programs are focused on mapping the trapped field along the symmetry axis, at higher magnetic field, and at lower working temperature in a transverse magnetic field.
Afterwards the cylinder will be tested in a longitudinal field, but also prepared in a transverse field and then immersed in a longitudinal field to test its capability on shielding the latter.
In the context of an electron scattering experiment, such a solution will minimize beam deflection and energy loss of the reaction products, while also will eliminate the heat load to the target cryostat from current leads that are required for superconducting electromagnets.
In the context of polarized fuel for fusion its use is straightforward, because the system can trap the

magnetic field required during fuel production, and then provide the holding field for its transfer in fusion test facilities.

Form Factors and GPDs / **159**

Three-loop corrections to the quark and gluon decomposition of the QCD trace anomaly and their applications

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In the QCD energy-momentum tensor $T^{\mu\nu}$, the terms that contribute to physical matrix elements are expressed as the sum of the gauge-invariant quark part and gluon part. Each part undergoes the renormalization due to the interactions among quarks and gluons, although the total tensor $T^{\mu\nu}$ is not renormalized thanks to conservation of energy and momentum. We show that, through the renormalization, each of the quark and gluon parts of $T^{\mu\nu}$ receives a definite amount of anomalous trace contribution, such that their sum reproduces the well-known QCD trace anomaly. We provide a procedure to derive such anomalous trace contributions to all orders in perturbation theory, and present the corresponding explicit decomposition formulas up to three-loop order in the (modified) minimal subtraction scheme in the dimensional regularization. We apply our three-loop formulas of the quark/gluon decomposition of the trace anomaly to calculate the anomaly-induced mass structure of nucleons as well as pions. Another application of our three-loop formulas is a quantitative analysis for the constraints on the twist-four gravitational form factors of a hadron, $\bar{C}_{q,g}$, which receive much attention in connection with the force distribution inside the nucleon and the nucleon's transverse spin sum rule. This talk is based on our work, JHEP 1901 (2019) 120, and some additional results.

Fundamental Symmetries and and Spin Physics Beyond the Standard Model / **160**

The MOLLER experiment

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The precision extraction of the weak mixing angle at low momentum transfer can significantly constrain extensions to the Standard Model. One such measurement will be undertaken by the MOLLER collaboration starting in 2025. Using longitudinally polarized electrons scattering from unpolarized electrons in a liquid hydrogen target the experiment will be able to measure the approximately 34 parts per billion parity violating asymmetry to a precision of 2%. Such high precision requires fine control of systematics and innovations in magnet and detector design. The status of the project, experimental description and potential implications of the result will be discussed.

Spin in Nuclear Reactions and Nuclei / **161**

Weak charge distribution of 208Pb

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While the electromagnetic charge distribution of protons inside nuclei has been well determined using electron scattering experiments, significant progress still needs to be made to reach the same level of precision for neutrons. The parity violating asymmetry in longitudinally polarized elastic electron-nucleus scattering is sensitive to the neutron RMS radius. The PREX-2 collaboration has completed a measurement using this technique looking at the neutron-rich ^{208}Pb nucleus. The clean theoretical connection between the parity violating asymmetry and other parameters of the nuclear equation of state allows for comparisons with other measurements (such as neutron star radii). In this talk we will present the recently published high precision result from data collected in 2019 using the CEBAF accelerator at Jefferson Lab.

Spin in Nuclear Reactions and Nuclei / **162**

CREX: The Calcium weak Radius Experiment

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The ^{48}Ca nucleus provides an important testing ground for models (both density functional and ab-initio) trying to describe the arrangement of both protons and neutrons in nuclei. The parity violating electron scattering asymmetry from the unpolarized ^{48}Ca nucleus gives direct access to its weak form factor. Using data collected with the CEBAF accelerator at Jefferson Lab in 2020 the CREX collaboration has completed a blinded analysis of this quantity. This talk will describe the experiment, data analysis and systematic control, as well as the implications of this result on our understanding of nuclear matter.

Joint TMD - GPD - HELCITY - Future session EU timezone / **163**

TMDs and EIC impact studies

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Semi-Inclusive Deep-Inelastic Scattering (SIDIS) is one of the processes that allow us to extract information about Transverse Momentum Distributions (TMDs) and will be the main channel to access TMDs at the future Electron Ion Collider (EIC).
We provide an estimate of the impact that EIC data will have on unpolarized Transverse-Momentum Dependent (TMD) Parton Distribution Functions (PDFs) and Fragmentation Functions (FFs). We performed a study that shows that including EIC pseudo data in a global fit allows us to better determine the non-perturbative parameters of unpolarized TMD PDFs and FFs, which are much more constrained than in the global fit performed by the Pavia group in 2017.

Transverse Momentum Structure (TMD) / **164**

Progress in the extraction of unpolarized TMDs from global data sets

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We review the recent progress on the extraction of unpolarized TMD PDFs and TMD FFs from global data of Semi-Inclusive Deep-Inelastic Scattering, Drell-Yan and Z boson production. In particular, we address the tension between the low-energy SIDIS data and the theory predictions, and explore the impact of the very precise LHC data on the fit results.

Transverse Momentum Structure (TMD) / 165

Transverse Single-Spin Asymmetries of Midrapidity Direct Photons and Neutral Mesons at PHENIX

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Recently published measurements from the PHENIX experiment at the Relativistic Heavy Ion Collider will be presented for the transverse single-spin asymmetries (TSSAs) of direct photons, neutral pions, and eta mesons produced at midrapidity in 200 GeV proton-proton collisions. As hadrons, neutral pions and eta mesons are sensitive to nonperturbative spin-momentum correlations both within the proton and in the process of hadronization; at midrapidity they probe the dynamics of gluons along with a mix of quark flavors. The direct photon TSSA measurement instead isolates initial-state spin-momentum correlations within the proton and at midrapidity provides a clean probe of the gluon dynamics in transversely polarized protons. All three of these results will help to constrain the collinear twist-3 trigluon correlation function. The direct photon result is the first-ever measurement of this observable from a hadron collider, and all three of the measurements represent the final, definitive results for these observables from the PHENIX experiment, which completed data taking with polarized beams in 2015.

Acceleration, Storage and Polarimetry of polarized Beams / 166

Spin depolarization in high energy electron storage rings: stochastic differential equations, the reduced Bloch equation and the invariant-spin-field approximation

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A spin distribution in a high energy e^+ or e^- storage ring is governed by a $(6+1)$ dimensional linear Fokker-Planck-type equation known as the full Bloch equation. Its reduction, the reduced Bloch equation (RBE), is the spin-orbit diffusion equation which takes into account just those terms in the spin-orbit dynamics that suffice for calculating the spin-depolarization rate. While the RBE gives the full picture of the depolarization phenomenon, it has limitations, both in terms of analysis and numerical simulations. Here we introduce a framework for studying the Bloch equation based on a stochastic differential equation (SDE). The framework combines SDEs, modelling the spin-orbit motion of the electrons(positrons), Fokker-Planck type equations for orbit and spin-orbit density functions, and approximations for studying them. The SDEs in the framework are derived from the Lorenz force law coupled with Thomas-Bargmann-Michel-Telegdi spin precession and, as the name suggests, include a stochastic process modelling the effect of synchrotron radiation. This SDE framework reproduces the known equations modelling the depolarization phenomenon, like the Bloch equation and the Derbenev-Kondratenko (DK) formulas. It can also be used, as we do here, either to generalize the DK formulas and the Bloch equation, or to simplify the latter to a form that makes it amenable for solution by numerical methods.

The Bloch equation models the spin distribution as a three-scale time dependent process. The first scale comes from the rapidly varying transverse motion, governed by accelerator optics; the second scale arises from the classical spin precession, with rates varying with reference energy of the electron bunch; and finally the synchrotron motion, which is slowly varying yields the last scale. Coupling between the synchrotron motion and transverse betatron motion introduces spin-orbit resonances that have a devastating effect on spin-polarization in most optical settings and reference energies. Multiple scales involved require hybrid approaches. We will present three approaches to approximate solutions of the Bloch equation that can be hybridized within the SDE framework. The first approach uses perturbation theory and delivers the results consistent with formalism previously derived from QED. The second approach is built on averaging analysis of the slowly varying form of the SDEs and brings in the effective models to study spin-depolarization. The third approach is the numerical integration of the Bloch equations with a spectral method based on Fourier-Chebyshev expansions.

Finally, at the end of talk we use a simple model that contains most of the difficulties present in equations for a realistic accelerator. We will demonstrate the efficacy of the SDE framework and the approximations. We finish by presenting an approach in which coefficients in these equations are averaged to produce a so-called effective Bloch equation and then present a scheme for the numerical integration of the latter.

Fundamental Symmetries and and Spin Physics Beyond the Standard Model / 167

CP-violating gluon operators and neutron EDM from the QCD instanton vacuum

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Experimental studies of hadronic CP-violation rely on theoretical calculations of the hadronic matrix elements of higher-dimensional QCD operators representing the effects of the CP-violating short-distance dynamics at the hadronic scale. We report about a recent calculation of the spin-dependent nucleon matrix element of Weinberg's dimension-6 CP-odd gluon operator $f^{abc}(\tilde{F}_{\mu\nu})^a(F^{\mu\rho})^b(F^{\nu}{}_{\rho})^c$ using the instanton picture of the QCD vacuum [1]. In leading order of the instanton packing fraction, the dimension-6 operator is effectively proportional to the topological charge density $(\tilde{F}_{\mu\nu})^a(F^{\mu\nu})^a$, whose nucleon matrix element is given by the flavor-singlet axial charge and constrained by the $U(1)_A$ anomaly. The nucleon matrix element of the dimension-6 operator is obtained substantially larger than in other estimates, because of the strong localization of the nonperturbative gluon fields

in the instanton vacuum. We comment on the neutron EDM induced by the dimension-6 gluon operator. We discuss the connection of the CP-violating operators with other operators describing nucleon spin structure in deep-inelastic processes.

[1] C. Weiss, Phys. Lett. B 819 (2021) 136447

Spin in Nuclear Reactions and Nuclei / **168**

Spin contents of Na isotopes towards driplines

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The structure evolution of neutron-rich isotopes provides with many intriguing facets. Recently, we presented [1] how such evolution occurs in F-Ne-Na-Mg isotopes up to their neutron driplines, by using an ab initio effective nucleon-nucleon (NN) interaction derived from the chiral Effective Field Theory of QCD [2]. In this presentation, we shall report some features of the spin contents obtained quite recently by extending this approach. These features are focused on because of the main interest of the conference. We thus discuss the magnetic moments of Na isotopes up to their dripline, in agreement with experimental values [3].
The wave functions used in this work can produce another nice agreement with experiment for the charge/matter radii and the quadrupole moments, as well as the ground-state energies [1]. The dripline is located at ^{39}Na, being most likely consistent with experiment [1,4].

One of the remarkable findings is that the magnetic moments of the ground states of Na isotopes up to ^{31}Na can be well described by free spin g-factors (g_s). On the other hand, it appears that the orbital g-factors (g_l) are changed from the free values by an isovector shift of 0.2. Such an isovector shift of the orbital g-factors is quite usual, and is ascribed to the meson effect which can be needed independently of the nuclear structure calculation. On the other side, the spin quenching has been considered to be due to the 2p2h excitations across the relevant magic gap (core polarization or configuration mixing), which are explicitly included, in our calculation, between the sd and pf shells thanks to the present ab initio effective NN interaction capable of describing such cross-shell excitations. We note that only the present interaction may have this capability among various ab initio interactions proposed so far, due to its derivation by the EKK method [5]. It is of interest to examine predicted values for Na isotopes beyond ^{31}Na.

The predicted magnetic moments of exotic Na isotopes indeed point to strongly deformed shapes, as expected in the scenario presented in Ref. [1]. The neutron spin contents of exotic Na isotopes are quite small up to the dripline nucleus. The proton spin contents are more sizable, but differ from those in the single-particle picture. Thus, the exotic Na isotopes are expected to be a very interesting domain in the nuclear chart, including their magnetic properties.

[1] N. Tsunoda, T. Otsuka, K. Takayanagi, {\it et al.}, Nature {\bf 587}, 66 (2020).
[2] R. Machleidt and D. R. Entem, Phys. Rep. {\bf 503}, 1 (2011).
[3] National Nuclear Data Center's 'Evaluated Nuclear Structure Data File' (http://www.nndc.bnl.gov/ensdf/).
[4] D. S. Ahn, {\it et al.}, Phys. Rev. Lett. {\bf 123}, 212501 (2019).
[5] N. Tsunoda, K. Takayanagi, M. Hjorth-Jensen, and T. Otsuka, Phys. Rev. C {\bf 89}, 024313 (2014).

Transverse Momentum Structure (TMD) / **170**

Fragmentation function measurements from Belle

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Electron-positron annihilation into hadrons is one of the fundamental tools for studying non-perturbative QCD effects. Fragmentation functions, describing the formation of hadrons from partons, are an indispensable tool in the interpretation of hadron-production data, e.g., in the investigation of nucleon structure via semi-inclusive deep-inelastic scattering. The cleanest process to access fragmentation functions is hadron production in electron-positron annihilation. However, little information can be derived on charge-separated fragmentation functions from single-inclusive hadron production. A better handle on the flavor contributions can be gotten by flavor correlations or tagging: the hadron type in one hemisphere puts constraints on the parton flavor in the other hemisphere and thus on the flavor decomposition of the hadronization process. This can be exploited in inclusive hadron-pair production in electron-positron annihilation. While two hadrons in the same hemispheres, e.g., originating from the same parton, open an avenue to an unusual class class of fragmentation functions, dihadron fragmentation functions, two hadrons in opposite hemispheres can be used for flavor and polarization tagging of single-hadron fragmentation functions. These scenarios have recently been subject to renewed studies at the Belle experiment. As one part of this contribution, without explicit relation to polarization effects, the dependences of the production cross section of pairs of identified light mesons (charged pions and kaons) as well as of (anti)protons on the individual z of the hadrons as well as on alternative scaling variables will be presented. Furthermore, the first measurement of the transverse-momentum dependence of single-hadron fragmentation, for charged pions, kaons as well as for protons, will be discussed.
The Belle experiment at the asymmetric KEKB electron-positron collider has already published several ground-breaking results on fragmentation functions, among others, the first measurement of azimuthal correlations for pairs of almost back-to-back charged pions related to the novel Collins fragmentation effect. The latter is one example of polarization dependence in hadronization despite an unpolarized initial state. Recently, these Collins modulations for charged pions have been revisited in the study of their transverse-momentum dependence. The analysis was also expanded to include for the first time neutral pions as well as eta mesons. An additional novel polarization effect is the formation of transversely polarized Lambda hyperons in the fragmentation process. Transversely polarized hyperons have been produced copiously in unpolarized proton-proton collisions, however, the question of the origin of these partially rather large polarizations has remained unanswered. One possibility is a novel fragmentation function, which was the focus of a recent study at Belle. The results for the production of transversely polarized Lambda hyperons and the of abovementioned Collins modulations will be discussed in the second part of this contribution.

Plenary Presentations / **172**

Opening remarks

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Plenary Presentations / **173**

Theory of muon g-2

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The longstanding discrepancy between the measured and the predicted values of the anomalous magnetic moment of the muon, a_μ = (g-2)/2, is one of the most intriguing potential hints of new

physics in particle physics. After a brief introduction, the status of the theoretical prediction of g-2 will be presented, with some focus on the contributions yielding the dominant uncertainties. The results presented here are based mainly on the White Paper (arXiv:2006.04822) of the Muon g-2 Theory Initiative.

Plenary Presentations / 174

Progress on Lattice QCD studies on the spin physics

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Resent results obtained using state-of-the-art lattice QCD simulations on the nucleon spin decomposition will be reviewed. The results include valence and sea quark and gluon contributions. Open issues in particular connected to the fixing and renormalisation will be discussed.

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ELI-NP project overview

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Extreme Light Infrastructure - Nuclear Physics (ELI-NP) is a new research infrastructure installed in Bucharest-Magurele (Romania) dedicated to Nuclear Photonics with extreme photon beams. At ELI-NP high-power laser and gamma beams with unprecedented characteristics will be provided to be used for nuclear physics, laser plasma physics, quantum electrodynamics, material science research and related fields.
The high-power laser system consisting of 2 x 10 PW lasers with ultra-short pulses will reach irradiance values as high as 10^{23} W/cm^2 and will create ultra-dense, ultra-short, high-energy ion beams as well as coherent X-ray sources. The operation of the laser system at 10 PW has recently marked a world premiere in the field of high-power lasers.
The gamma beams to be delivered at ELI-NP will exhibit high spectral density of about 10^4 photons/s/eV, average relative bandwidth of less than 0.5%, continuously tuneable energy up to about 20 MeV, linear polarization of more than 95%.
The experimental setups are currently under commissioning and the first experiments with high-power lasers aim at measuring the magnitude and scaling of the achievable laser intensity via laser-gamma conversion efficiency, finding new ion acceleration schemes and achieving a better understanding and control of high-intensity laser-driven ion sources.
The outstanding characteristics of the gamma beams that will be provided at ELI-NP are opening new perspectives in Nuclear Photonics. Nuclear Resonance Fluorescence experiments will allow for the direct, model-independent determination of key information about the nuclear excited states, such as: excitation energy, spin quantum numbers, parities, branching ratios as well as level widths and gamma decay branching ratios. Photonuclear reactions experiments will largely benefit of the outstanding features of the gamma beams allowing for the study of electromagnetic dipole response of rare nuclei available in nature in extremely low quantities, such as *p-nuclei*.
A broad research program on technologies for biomedical applications, anchored in the unique ELI-NP capabilities, is currently being developed and addresses topics, such as: production of radiotherapy relevant nuclear beams, radiobiological effects of laser and gamma nuclear beams, medical imaging research with laser X-ray sources and medical isotope production research with laser-driven nuclear beams.

An overview of the ELI-NP research infrastructure and of selected research topics to be investigated at ELI-NP will be given.

Plenary Presentations / **176**

Polarization aspects of CMB

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I will present some aspects of the measurements of the polarization of the Cosmological Microwave Background (CMB). In particular, I will detail what we have deduced about the cosmological parameters of the LambdaCDM concordance model and its extensions through the observation of the CMB polarization with the Planck satellite. I will also discuss future projects that aim to increase the precision of these measurements. Some of them are under construction or design, either on the ground or in space: the Simons observatory, CMB-S4 and LiteBIRD. For these, I will focus mainly on the predictions of the B-modes observation, with emphasis on the expected results on our understanding of fundamental physics, and in particular on the physics of the primordial universe, and the mass of neutrinos.

Plenary Presentations / **177**

Spin Polarization Effects in Heavy Ion Collisions

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itle: Spin polarization effects in Heavy Ion Collisions
Presenter: Zuo-tang Liang (Shandong University)

Abstract:
In non-central high energy heavy ion collisions, the colliding system possesses a huge orbital angular momentum along the normal direction of the reaction plane. Due to the spin orbit interaction in the relativistic quantum system, such a huge orbital angular momentum leads to the spin polarization of quarks and anti-quarks in the quark matter system produced in the collision. Such an effect, known as the global polarization effect (GPE), was predicted many years ago and has been confirmed by the STAR collaboration at RHIC. The discovery of GPE by the STAR collaboration opens a new window in heavy ion physics in general and in studying the properties of quark-gluon plasma in particular. In this talk, I will briefly review the original ideas and calculations that lead to the prediction and summarize progresses and problems in related aspects.

Plenary Presentations / **178**

Spin-polarized exotic nuclei and beta-NMR: from fundamental interactions, via nuclear structure, to material science, biology and medicine.

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This talk is devoted to versatile studies with spin-polarized radioactive nuclei, which make use of asymmetric emission of decay radiation. This feature is often combined with nuclear magnetic resonance, resulting in the beta-NMR technnique, which is up to 10 orders of magnitude more sensitive than conventional NMR. In my CERN-ISOLDE experiment we have just used it to determine magnetic dipole moments of short-lived nuclei with part-per million accuracy.
In this talk I will introduce the principles of laser polarisation, asymmetric beta decay, and beta-NMR. I will then concentrate on recent highlights from different fields of research: mirror decays for CKM-matrix unitarity studies, beta-NMR in solids for material science and in liquids to determine accurate nuclear magnetic moments, and to perform studies in chemistry and biology. I will also mention the gamma-MRI approach, which can combine the high sensitivity of PET and SPECT techniques with high spatial resolution of MRI.

Plenary Presentations / **179**

An EDM search experiment with ultracold polyatomic molecules

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Polar molecules, due to their intrinsic electric dipole moment and their controllable complexity, are a powerful platform for precision measurement searches for physics beyond the standard model (BSM) and for quantum simulation/computation. This has led to many experimental efforts to cool and control molecules at the quantum level. I will discuss our results on the laser cooling of molecules into the ultracold regime, the search for the electric dipole moment of the electron (EDM), and future prospects for the use of polyatomic molecules to greatly improve the search for the EDM, which would broadly probe for - in the not to distant future - PeV level CP violating new particles. I will briefly discuss the creation of an optical tweezer array of ultracold CaF molecules, as well as the search for the EDM using cold ThO molecules (the ACME experiment, which has already broadly probed for > 1 TeV physics). I will focus on the prospects for laser cooling of the polyatomic molecules, in particular the laser cooling of YbOH for a new experiment, dubbed PolyEDM. More broadly, polyatomic molecules have attracted new focus as potential novel quantum resources that have distinct advantages (and challenges) compared to both atoms and diatomic molecules. I will discuss how some key features of polyatomic molecules can be used to enhance applications in fundamental symmetry tests, searches for dark matter, and the search for CP-violating BSM physics.

Plenary Presentations / **180**

Crystallography of Dynamically Polarized Proteins with Polarized Neutron Beams

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Protein crystallography is an established technique for determining the structure of many protein systems. X-ray protein crystallography is the dominant technique, as the incredibly high flux of modern light sources allows researchers to collect data very quickly using very small crystals. In comparison, neutron crystallography has many unique advantages (due the neutron's sensitivity to isotopes and light nuclei) but suffers from the low flux available at neutron sources. The spin dependence of slow neutron scattering provides an opportunity to overcome the flux limitations of neutron sources, expanding the number of protein systems that can be studied, improving the signal to noise, and enabling novel measurement techniques to determine the location of hydrogen atoms. At Oak Ridge National Laboratory, a program has been underway to develop Dynamic Nuclear Polarization (DNP) techniques, and apply them to neutron scattering, especially Neutron Macromolecular Crystallography of proteins. The status and results of the Dynamic Nuclear Polarization program at Oak Ridge National Laboratory will be discussed, with an emphasis on the use of DNP to enhance measurements of diffraction from protein crystals.

Plenary Presentations / **181**

Theoretical studies on the 3D structure of the nucleon

Author: Barbara Pasquini[1]

[1] *University of Pavia and INFN, Pavia*

I will discuss recent progress in the theoretical investigation of the partonic structure of the nucleon in terms of generalized parton distributions and transverse momentum dependent parton distributions. In particular, I will highlight the information encoded in these functions on the spin and multidimensional partonic structure of the nucleon.

Plenary Presentations / **182**

Experimental studies on the high-energy spin physics in the fixed-target experiments

Author: Fabienne KUNNE[1]

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Results on high energy spin physics obtained at various facilities with fixed-target experiments will be presented. This includes measurements at JLab, Compass at CERN and HERMES at DESY. The topics covered are essentially the parton helicity and transversity, Sivers effect, GPDs and HEMPs. The extracted polarized PDFs and TMDs will be shown.

Plenary Presentations / **183**

Theoretical studies on the nucleon helicity structure

Authors: Christopher Cocuzza[1]; nobuo sato[2]

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In this talk we will provide an overview of the current theoretical status of observables that provide access to helicity PDFs and summarize the opportunities and challenges at the future EIC.

Plenary Presentations / **184**

High-energy polarized proton experiments in the USA

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Great progress in high energy polarized proton experiments was made in the USA. Historically these experiments were carried out mainly at ZGS, LAMPF, AGS, FNAL, first with polarized targets and then with polarized proton beams from 1970s. These efforts are followed now at RHIC. I will briefly review the progress of the spin physics with high energy polarized protons, especially in relation with the contribution of Prof. Alan Krisch and Dr. Aki Yokosawa who have passed away rather recently. In this spin symposium, it is meaningful to remember their achievements in the progress of the high energy spin physics.

Plenary Presentations / **185**

High-energy polarized proton accelerators in the USA

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The acceleration and storage of high energy polarized proton beams has made tremendous progress over the last fifty years challenging along the way the technologies, precision and the understanding of the beam dynamics of accelerators. After a brief summary of the development and history of polarized proton beam acceleration and the key contributions made by Ernest Courant and Satoshi Ozaki I will focus on the highest energy polarized proton collider, RHIC, and on the possibility of accelerating polarized beams to even higher energies in the future.

Plenary Presentations / **186**

Experiments with photon beams at the HIGS facility

Author: Calvin Howell[1]

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The angular-momentum selectivity in photon-induced nuclear reactions enables strategic investigations of nuclear and nucleon structure via excitation of the internal electric charge and current distributions as expressed through single-particle and collective motion responses. The narrow energy

resolution and high polarization of laser Compton gamma-ray (γ-ray) beams offer a complementary probe to bremsstrahlung beams for studying nuclear phenomena. The High Intensity Gamma-ray Source (HIγS) at the Triangle Universities Nuclear Laboratory (TUNL) is the highest intensity Compton gamma-ray source in the world [1]. The γ-ray beam at HIγS is produced by Compton-back scattering of electrons from photons inside the optical cavity of a storage-ring based free electron laser. This unique facility provides circularly and linearly polarized γ-ray beams with beam polarization greater than 95% and beam energy resolution as low as 2% over the energy range from 2 to 110 MeV. These beam capabilities enable a broad research program that includes nuclear structure and reactions, nuclear astrophysics, fission, few-nucleon reaction dynamics, nucleon structure, and detector R&D.

An overview of the current research program at HIγS will be presented that includes highlights of recent results in several research areas, e.g., studies of collective electromagnetic nuclear responses using nuclear resonance fluorescence, photon-induced reactions important in nuclear astrophysics, photofission, few-nucleon reaction studies, and the determinations of the low-energy electric and magnetic structure parameters of the nucleons using Compton scattering. The talk will conclude with a discussion about future directions for the HIγS research program and the facility.

[1] H.R. Weller *et al.*, "Research Opportunities at the Upgraded HIGS Facility," Prog. Part. Nucl. Phys. **62**, 257 (2009).

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Plenary Presentations / 187

LEPS experiments with polarized photons

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A linearly polarized photon beam acts as a filter to disentangle the production mechanisms and suppress background processes in the photoproduction of mesons and baryons. Compton backscattering of laser light off the 8 GeV electrons circulating in the SPring-8 storage ring provides a high-intensity beam of linearly polarized photons in a range of 1.4 - 2.9 GeV. The LEPS facility featured a large dipole spectrometer and operated in the last 20 years. LEPS data encompasses final states produced forward, such as K^+, K^*, and ϕ from photoproduction and manifested in experimental observables such as the cross-section and beam asymmetry. In addition, associated hyperon production with K^* is fascinating to unveil the nature of $\Lambda(1405)$. The LEPS2 facility, consisting of a large solenoid magnet and a time projection chamber, has recently completed its first phase of beam commissioning and physics running. Analysis effort of the first dataset is now underway. We will present selected recent highlights with LEPS and the prospects of the LEPS2 facility.

Plenary Presentations / 188

Progress on the new solid polarized target by using the symmetry of Perovskite structure

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It is widely known that a solid polarized target is a powerful device for researches in spin physics, such as investigation of spin structure of nucleons, nuclear structure, and spin correlation in nuclear reactions. Although about 50 years have already passed since the beginning of studies on the Dynamic Nuclear polarization(DNP), the solid polarized targets are still limited to protons and deuterons in practical beam experiments. A possible method for breaking the above situation is the DNP by using the symmetry of Perovskite structure. This method holds possibilities for realizing the practical polarized targets of nuclei with high quadrupole moments, which are expected as completely new tools for opening up potentialities in Spin Physics. The NOPTREX collaboration applies it to the development of polarized lanthanum(La) targets for discovery of Time-reversal violating effects with ultra-high sensitivity. In this presentation, we will not only introduce the method and its features, but also report current status of development of the polarized La target in the NOPTREX project.

Plenary Presentations / **189**

EIC accelerator

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The Electron-Ion Collider will be a new discovery machine for unlocking the secrets of the "glue" that binds the building blocks of visible matter in the universe. The EIC will consist of two intersecting accelerators, one producing an intense beam of electrons (Electron Storage Ring), the other a high-energy beam of protons or heavier atomic nuclei (Hadron Storage Ring), which are steered into collisions of spin-polarized beams in the Interaction Region. The EIC design will make use of existing ion sources, a pre-accelerator chain, a superconducting magnet ion storage ring, and other infrastructure of the Relativistic Heavy Ion Collider (RHIC) at Brookhaven National Laboratory. The Rapid Cycling Synchrotron will provide injection into ESR, while preserving beam polarization. The Strong Hadron Cooling system will preserve emittances of the proton beam during collision run. The EIC project has recently received Critical Decision 1 (CD-1) approval from DOE, and the project team is now working on the next milestone – CD-2. The EIC project will be delivered in a collaboration of domestic and international partners. In this talk, the status of EIC accelerator will be reviewed.

Nucleon Helicity Structure / **190**

J/psi spin asymmetry measurements in p+p collisions at 200 and 510 GeV by the PHENIX experiment at RHIC

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Studies of heavy quark bound states, like J/psi meson, provide a useful tool to investigate QCD properties. Many general features of J/psi production, such as cross-sections and transverse momentum distributions are well described by many existing models. In order to differentiate between various theoretical models one has to study J/psi production in more details. One of the observables which can be used for this purpose is angular distribution of leptons produced in quarkonium decays, usually called polarization or spin asymmetry.
The PHENIX experiment at RHIC has measured inclusive J/psi polar and azimuthal angular decay coefficients at the mid ($|y|<0.35$) and forward ($1.2<|y|<2.2$) rapidity in p+p collisions at 200 GeV and

510 GeV. In this talk the analysis details as well as the results in different polarization frames will be presented and compared to theory.

Low energy spin physics with lepton, photon and hadron probes / 191

Differential cross sections and photon beam asymmetries of eta photoproduction on the proton in the LEPS2/BGOegg experiment

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The meson photoproduction is a useful tool to study baryon resonances.Especially, an η meson is an isoscalar meson with $s\bar{s}$ components, so it is expected to couple with N^* states with large $s\bar{s}$ components. In previous experiments, the bump structure was seen above 2 GeV in differential cross sections of η photoproduction. But in this energy region, many resonance states exist, so it is difficult to distinguish each contribution by just measuring the differential cross sections. Therefore, it is necessary to measure the photon beam asymmetry, which is one of the spin observables.
The experiment was carried out in the LEPS2 beamline at SPring-8 using GeV photon beam. This photon beam is highly linear polarized, and this polarization degree is more than 90 $\%$ in high energy regions. Produced particles were measured using the BGOegg calorimeter and the forward chambers. The photon beam asymmetries above 2.1 GeV were measured for the first time. We report the experimental results and comparisons with the partial wave analysis.

Low energy spin physics with lepton, photon and hadron probes / 192

Search for the H-dibaryon near $\Lambda\Lambda$ and $\Xi^- p$ thresholds via $^{12}\mathrm{C}(K^-, K^+)$ reactions at J-PARC

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The J-PARC E42 is a dedicated experiment to search for an H-dibaryon near $\Lambda\Lambda$ and $\Xi^- p$ threshold. The H-dibaryon is the lightest $S = -2$ system which can be decomposed into a symmetric six-quark object made from *uuddss* quarks and two baryon states involving $\Lambda\Lambda$, ΞN, and $\Sigma\Sigma$ components. E42 detector is highlighted by a large-acceptance Superconducting Hyperon Spectrometer (SHS), which accommodates a GEM-based time projection chamber (HypTPC). A high-intensity K^- beam was incident on a diamond target inside the HypTPC, and outgoing K^+ particles were tagged using a dipole KURAMA spectrometer. The reaction (K^-, K^+) proves the production of $S = -2$ systems at a beam momentum of 1.82 GeV/c. The E42 has completed physics runs in 2021. E42 data includes all charged particles from subsequent decays in $^{12}\mathrm{C}(K^-, K^+)$ reactions. Analysis effort of the dataset is now underway. Spin analysis of two Λs would help an experimental confirmation of the existence of a spin-singlet H-dibaryon. We will present expected results with E42 and hadron physics programs with SHS.

Acceleration, Storage and Polarimetry of polarized Beams / **193**

The spin-injector for the P2 experiment at MESA

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The P2-experiment will measure the weak charge of the proton with high precision at the MESA accelerator facility.
Using elastic scattering of longitudinally spin polarized electrons off the proton, the parity-violating asymmetry has to be measured with high accuracy.
New approaches have been chosen to fulfill the increased demands compared to older experiments which to large extent concern the injection system of MESA.
These include in particular a double Wien filter for independent setting of the polarization sign and redundant polarimetry.
The beam dynamics of the spin-injector is simulated in start-to end fashion, taking space charge effects into account.

Polarized Sources and Targets / **194**

The Hydro-Moeller Polarimeter at MESA

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A precision online polarimeter for the P2 experiment at the upcoming MESA accelerator is highly desirable. It can be realized in the following manner: A solenoid trap is integrated into the beamline leading towards the experiment. The trap will contain hydrogen atoms, the high magnetic field leads to a complete electron-spin polarization. Such an arrangement allows online operation because of low target thickness. Further, the main systematic errors of a Moeller polarimeter will be suppressed, potentially leading to very high polarisation accuracy. We present the technical design and how the trap and its peripheral devices can be integrated into the beamline.

Plenary Presentations / **195**

Report from ISPC meeting

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Polarized Sources and Targets / **196**

Testing a new polarized target for CLAS12 at Jefferson Lab

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Run Group C comprises seven experiments utilizing the CLAS12 detector system in Hall B at Jefferson Lab aiming to study the multidimensional partonic structure of nucleons. The experiments will scatter electrons from polarized protons and neutrons in samples of solid NH3 and ND3, dynamically polarized in a 5 T magnetic field and a temperature of 1 K. After a brief description of the target system, the current status of the target will be presented as will results of recent tests in the laboratory of the Jefferson Lab Target Group.

Applications of Nuclear Polarization in other Fields / **197**

Nuclear Barnett effect and Nuclear Einstein-de Haas effect

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Nuclear Barnett effect and Nuclear Einstein-de Haas effect

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Spin mechanical coupling played a crucial role in developing the quantum mechanics. The coupling between the spin of an electron and mechanical rotation provided the first experimental proof that an electron has an angular momentum i.e., spin by Barnett, and Einstein and de Haas in 1915 [1, 2]. By using these studies, they were experimentally determined the value of the g factor of an electron to be ~2 prior to the establishment of the modern quantum physics. The Barnett effect is the phenomenon, in which a mechanically rotating magnet is magnetized. The reverse of the Barnett effect is referred to as the Einstein- de Haas (EdH) effect, in which magnetization generates mechanical rotation of a magnet. These effects have been studied in the electron spin system. We have expanded these effect to the nuclear spin system. We observed the Barnett field, which is the origin of the Barnett effect, by using coil-rotation NMR and NQR method[3, 4]. Now, we are trying to observe the nuclear EdH effect by exploiting the dynamic nuclear polarization.

[1] S. J. Barnett, Phys. Rev. 6, 239 (1915).
[2] A. Einstein and W. J. de Haas, Deutsche Physikalische Gesellschaft 17, 152 (1915).
[3] H. Chudo, et.al., Appl. Phys. Express 7, 063007 (2014).
[4] H. Chudo, et.al., Phys. Rev. B 103, 174308 (2021).

Applications of Nuclear Polarization in other Fields / **198**

Design and development of the molecular probes for application of the hyperpolarized-NMR/MRI

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Hyperpolarized-nuclear magnetic resonance and imaging (HP-NMR/MRI) is a promising technique that allows direct monitoring of metabolic reactions *in vitro* and *in vivo*. Given the 13C- or 15N-labeled molecular probes whose NMR signal is amplified by the dynamic nuclear polarization (DNP) under a cryogenic magnetic field (3.35T, 1.4K), the sample is rapidly dissolved with a superheated solvent (~458K), and then quickly reacted with enzymes or cells, or administered in animals put into the magnet. The metabolic reaction is readout onto the NMR spectra or MR image based on the >10,000-fold enhanced signals. By elucidating the extent of the metabolic reaction of the probes, early detection of disease-specific elevation of enzymatic activity, metabolic reprogramming, and alteration of their flux upon the treatment is possible.
The development of various molecular probes will be a key factor to expand the utility of this approach. In this presentation, we will concisely introduce the basics of the dis-DNP, design and application of our recent new molecular probes that allow *in vitro* and *in vivo* HP-NMR/MRI.

1. Ardenkjær-Larsen J. H. *et al.* ***Proc. Natl. Acad. Sci. USA.*** 100, 10158, 2003
2. Golman K. *et al.* ***Proc. Natl. Acad. Sci. USA.*** 103, 11270, 2006
3. Saito K. *et al.* ***Clin. Cancer Res.*** 24, 3137, 2015
4. Scroggins B. T. *et al.* ***Clin. Cancer Res.*** 24, 3137, 2018
5. Matsumoto S. *et al.* ***Cancer Res.*** 78, 3783, 2018
6. Takakusagi Y. *et al.* ***Proc. ISMRM*** 26, 3720, 2018
7. Kondo Y. *et al.* ***Angew. Chem. Int. Ed.*** (Review) 60, 14779, 2021

Applications of Nuclear Polarization in other Fields / 199

Materials chemistry of triplet dynamic nuclear polarization

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Nuclear magnetic resonance (NMR) spectroscopy and magnetic resonance imaging (MRI) are powerful and versatile methods in modern chemistry and biology fields. Nevertheless, they suffer from intrinsically limited sensitivity due to the low nuclear spin polarization at ambient temperature. One of the promising methods to overcome this limitation is dynamic nuclear polarization (DNP) that transfers spin polarization from electrons to nuclei. In particular, DNP based on photo-excited triplet (triplet-DNP) is promising, since it allows the hyperpolarization at room temperature. In typical scheme of triplet-DNP, the spin-selective intersystem crossing (ISC) produces the large electron spin polarization in the excited triplet state sublevels, and this polarization is effectively transferred to nuclear spins by a pulsed microwave irradiation for satisfying Hartmann-Hahn condition, so-called integrated solid effect (ISE).
While much efforts have been devoted to obtaining the large nuclear polarization based on triplet-DNP, the application of triplet-DNP has been limited to nuclear physics experiments. Towards biological applications, we have proposed to introduce materials chemistry into the field of triplet-DNP, which realizes the hyperpolarization of nanomaterials such as nanoporous metal-organic frameworks (MOFs) and nanocrystal dispersion in water. In addition, we have developed the first examples of air-stable and water-soluble polarizing agents, which allows us to hyperpolarize crystalline ice.

Plenary Presentations / 200

Electron and Nuclear Spin Current Physics and Applications

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Spin current, a spin counterpart of electric current, refers to a flow of electrons' and nuclear spin angular momentum in condensed matter. Spin current has been ignored in electromagnetism in matter for many years, since it disappears in a very short distance, typically at the sub-micrometer scale. However, recent developments in nanotechnology have enabled us to make minute structures. For example, in integrated circuits composed of nanoscale wires, spin current may become as important a quantity as electric current. Spin current can be detected using the inverse spin Hall effect [1]: conversion of spin current into electricity in condensed matter. As a result, a lot of spin-current-related phenomena have been discovered [2-6].
In my talk, I will guide you around the world of spin current science. I will give an introduction to the basic concept of spin current, followed by a review of various phenomena discovered using spin current as a guiding principle, such as spin-Seebeck effects[2,4] and nuclear spin Seebeck effect [5,6]. The physics and materials science behind these effects will also be discussed.

[1] E. Saitoh et al., Applied Physics letters 88 (2006) 182509.
[2] K. Uchida et al., Nature 455 778-781 (2008).
[3] Y. Kajiwara et al., Nature 464 262-266 (2010).
[4] G. E. W. Bauer et al., Nature materials 11 391-399 (2012).
[5] Y. Shiomi et al., Nature Physics 15 22-26 (2019).
[6] T. Kikkawa et al., Nature Communications 12, 4356 (2021).

Polarized Sources and Targets / 201

Status of Polarized Solid Targets in European High Energy Scattering Experiments

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In Europe are running three polarized solid state targets in single and double polarized scattering experiments. In Bonn at ELSA and in Mainz at MAMI are two targets located. Both are so called frozen spin targets, which are dynamically polarized and during data taking the material is cooled down to 50 mK and lower, where the spins are frozen what means the relaxation time is increased to few hundred up to several thousand hours, depending on temperature and applied magnetic field. The biggest polarized target in the world is the COMPASS target, running in the north area at CERN. This target can run in frozen spin and in continuous wave mode depending on the physical question of the scattering experiment.
This talk presents the status of the three experiments with a focus on the targets.

Polarized Sources and Targets / 202

Concept of projection-type 3D spin-resolving electron detector with spatial resolution and new type of polarized electron source

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The concept of an imaging-type 3D spin detector, based on the combination of spin-exchange interactions in the ferromagnetic film and spin selectivity of the electron–photon conversion effect in a semiconductor heterostructure, is proposed and demonstrated on a model system. This novel multichannel concept is based on the idea of direct transfer of a 2D spin-polarized electron distribution to image cathodoluminescence (CL) [1]. The detector is a hybrid structure consisting of a thin magnetic layer deposited on a semiconductor structure allowing measurement of the spatial and polarization-dependent CL intensity from injected spin-polarized free electrons. The ferromagnetic/semiconductor detector has the potential for realizing multichannel 3D vectorial reconstruction of spin polarization in momentum microscope and angle-resolved photoelectron spectroscopy systems. A new type of spin polarized electron source based on the alkali antimonides photocathodes are discovered. It is shown that the degree of polarization is comparable to that observed for GaAs photocathodes.

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Opening

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Acceleration, Storage and Polarimetry of polarized Beams / **204**

Optimisation of spin-coherence time in a prototype storage ring for electric dipole moment measurements.

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The JEDI experiment is devoted to the search for the electric
dipole moment (EDM) of charged particles in a storage ring, as a very
sensitive probe of physics beyond the Standard Model. In order to reach the highest possible sensitivity, a fundamental parameter to be optimized is the particles' Spin Coherence Time (SCT), i.e., the time interval within which the particles of the stored beam maintain a net polarization greater than 1/e. To identify the working conditions that maximize SCT, accurate spin-dynamics simulations with the code BMAD have been performed on the lattice of a "prototype" storage ring which uses a combination of electric and magnetic fields for bending. The talk will present the results of these simulations addressing the impact on the SCT of different factors like horizontal tune, synchrotron tune and effect of the electric bending components.